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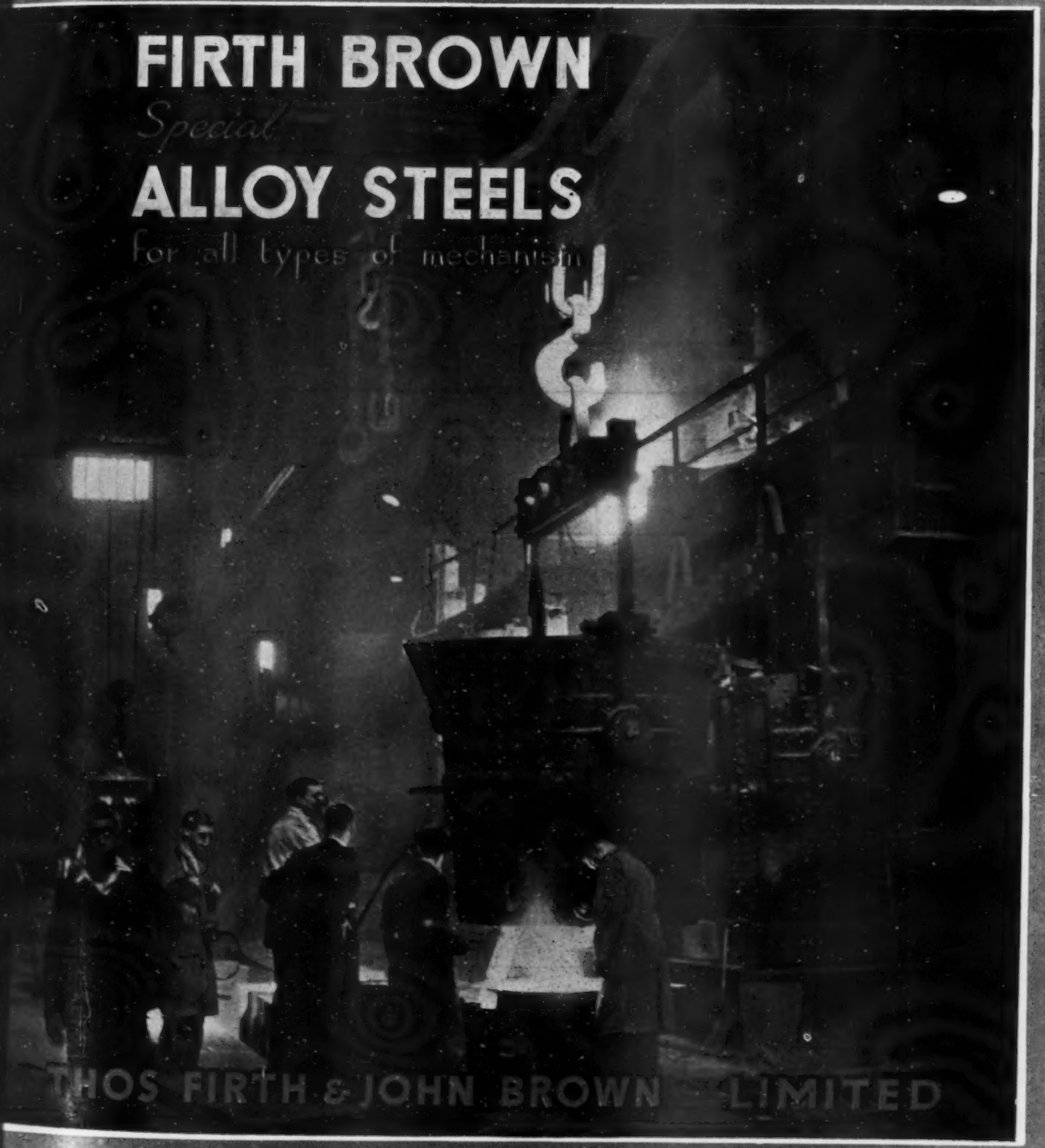

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METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER.)

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PRINCIPAL CONTENTS IN THIS ISSUE:

PAGE

Some Modern Methods of Metallurgical Analysis. By F. W. Haywood, B.Sc., Ph.D., F.I.C... 117–120

Present conditions necessitate the use of rapid methods of metallurgical analysis; many qualitative and quantitative methods are applied, but in this article a detailed description is given of an instrument for each of these methods which are both rapid and accurate.

What Britain is Doing 121

Economy in Tin Consumption .. 122

The Basic Open-Hearth Process Today. By W. Geary 123–128

This is the first of a series of articles on modern open-hearth furnace practice, in which the author briefly outlines developments in the open-hearth furnace from the application of the Siemens regenerative principle to the present time. Types and sizes of furnaces are briefly discussed, and constructional details are considered, particular attention being given to ports, roofs, linings, and to the regenerators.

A Metallurgical Study of German and Italian Aircraft Engine and Airframe Parts 129–136

This embraces the first two sections of a report which constitutes a summary of data resulting from the metallurgical examination of German and Italian aircraft and airframe parts by the Aero Components Sub-Committee of the Technical Advisory Committee to the Special Alloy Steel Committee formed for this purpose. The two sections presented briefly describe the engines examined and deal with the crankshafts. Subsequent issue will present data on other parts.

The Importance of Alloy-Scrap Segregation 136

Alloy-scrap should be segregated and returned to producer's plants.

PAGE

Electro-Tinplate. By W. E. Hoare, B.Sc. 137–139

Electro-tinning is a recognised industrial process, but its application in the production of tinplate is a comparatively recent development, and this review of the process indicates its possibilities for conserving tin without undue reduction in the quality of tinplate.

An Investigation of the Factors Governing the Adhesion of Tin-Base Bearing Metals. By W. T. Pell-Walpole, B.Sc., Ph.D., J. C. Prytherch, B.Sc., and B. Chalmers, D.Sc., Ph.D. 140–142

The bonds obtainable in forming lined bearings are considered, the strength of the bond is investigated and current methods of testing the adhesion of white metal bearings are discussed.

Performance Tests on Brake Drum Cast Irons 142–143

Factors which determine the life of brake drums are discussed, and results are given of some performance tests from a selected number of cast irons.

The Vagaries of 4S11. By Bernard Thomas, F.Inst.P. 144

Some results obtained from the heat-treatment of a small forging in nickel-chromium steel to specification 4S11 are described; they show that accepted temperatures of treatment do not meet all conditions.

The Chemical and Physico-Chemical Analysis of Iron and Steel. Part II—continued. By E. C. Pigott.. 145–147

Papers describing the determination of single constituents.

Investigations on "Falling" Blast-furnace Slag. By T. W. Parker, M.Sc., Ph.D., and J. F. Ryder, B.Sc. 147

An investigation on methods of detecting "falling" blast-furnace slags is described and the authors' conclusions are given.

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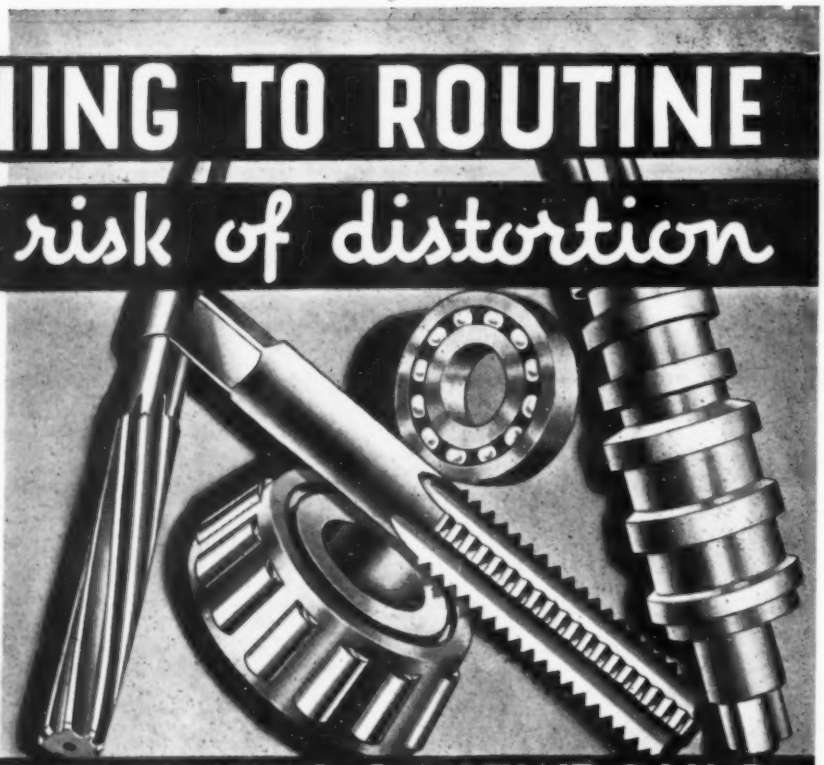

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METALLURGIA

THE BRITISH JOURNAL OF METALS.
INCORPORATING "THE METALLURGICAL ENGINEER."

AUGUST, 1942. VOL. XXVI, No. 154.

Some Modern Methods of Metallurgical Analysis

By F. W. Haywood, B.Sc., Ph.D., F.I.C.

(Chief Metallurgist to Wild-Barfield Electric Furnaces, Ltd., and G.W.B. Electric Furnaces, Ltd.

Present conditions necessitate the use of rapid methods of metallurgical analysis; many qualitative and quantitative methods are in use, but in this article a detailed description is given of an instrument for each of these methods which are both rapid and accurate.

AT the present time there is a big demand for rapid and accurate methods of analysis in all branches of metallurgical industry, and it is the purpose of this short article to give one or two methods which may prove of interest and assistance in this direction. The increased use of various classes of steel, non-ferrous and light alloys makes it imperative that whatever methods are used shall be reliable, capable of repetitive accuracy and rapid, and that in many instances the methods should be such that they can be used by unskilled labour. Furthermore, the absolute necessity, in some cases, of taking the particular instrument used to the job itself, combined with the fact that non-destructive testing may be essential, calls for instruments which are robust and entirely reliable.

Metallurgical analysis may be divided into two main subdivisions, namely, qualitative and quantitative methods, and it is proposed to give here particulars of an instrument for each of these methods.

Qualitative Analysis by the Use of the Spekker Steeloscope

The Spekker Steeloscope, as its name implies, is a specialised spectroscope for the rapid detection of elements in ferrous materials. It cannot be used for the detection of elements in non-ferrous materials, nor is it capable of detecting the non-metallic elements, such as carbon, sulphur, phosphorus, arsenic, oxygen and nitrogen in ferrous alloys. The instrument introduces for the first time into workshops, scrap-yards, and stores the well-known spectroscope—an instrument used in laboratories since 1866 for difficult analyses, and with which many elements were actually discovered. Broadly speaking, the general principle of operation of the instrument is to examine by the Steeloscope the light from the electric arc made between a pure iron sample and the ferrous alloy under examination. This spreads out the spectrum lines into a series whose positions are quite distinctive of the metal present in the specimen.

A general view of the instrument is shown in Fig. 1, where it will be seen that the apparatus consists of two metal tubes joined by a metal body, the whole assembly being mounted on a tripod with one leg adjustable. The left-hand tube, termed the collimator, is provided with a replaceable glass slide, used to prevent metal spluttering from the arc on to the initial collimating lens; immediately behind this glass slide is a glass window and a narrow slit through which light from the metal arc passes into the steeloscope, there to be spread out by the optical system of the instrument into its constituent radiations. The light passing through the slit is rendered parallel by a system of lenses, and this then falls on a system of prisms housed in the central portion of the instrument. The right-hand tube, termed the telescope, comprises a further optical system and terminates in an eyepiece, which is adjustable for individual focusing, and is mounted on a slide which can be moved across the field of view. As the slide on which the eyepiece is mounted is moved across the field of view, it is found to click into position at certain places at each of which an arrow on the eyepiece slide points to the chemical symbol of an element. (See Fig. 2.) When the metal thus indicated is present, one or more of its distinctive spectrum lines will be seen in the middle of the field of view when looking centrally through the eyepiece.

Fig. 1.—General view of the Spekker Steeloscope.

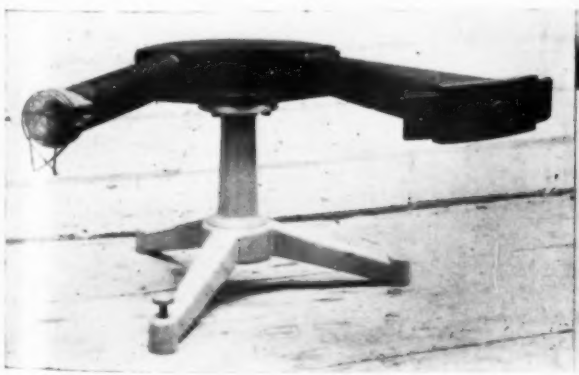


Fig. 2.—Enlarged view of eyepiece and slide of the Spekker Steeloscope.

Fig. 3.—Steeloscope working from an A.C. supply through a rectifier in a works' stores.

The Spekker Steeloscope can be used for the detection of nickel, chromium, molybdenum, manganese, titanium, tungsten, cobalt, copper, tin, cadmium, vanadium and columbium; it cannot, however, be used successfully for the detection of lead in lead-containing free-cutting steels.

The instrument is extremely simple in operation, and almost any size or shape of specimen can be examined, for example, small bars can be suitably supported on a simple form of stand, being connected by a pinch clip to one pole of the electric supply, a rod of pure iron being used as the other pole. Billets, forgings, heavy tubes and rods, plate and sheet can also be similarly examined. Filings and turnings can be tested by placing in a suitable cup—the arc being struck as usual between the sample under examination and an iron rod. It is essential that the surface of the sample in question should be free from rust and scale.

Probably one of the most important points in connection with the use of the Steeloscope is the absolute necessity for a D.C. supply. This should be of the order, in general, of 100–150 volts, a variable resistance being used in series to give an arc current of about 5–8 amperes. When D.C. supply is available the matter is simple. It frequently happens that no such supply is on tap, and in this case the following alternatives can be adopted; when single-phase A.C. supply is available metal type or valve type rectifiers can be used.

Fig. 3 shows the Spekker Steeloscope in use with a valve-type rectifier, all mounted on a suitable trolley carrying the Steeloscope, with sample stands and connections on top of the table, housing the valve rectifier underneath the table, with the controlling resistance and necessary length of cable to the A.C. supply on the side of the trolley. Such a layout is extremely mobile, enabling the instrument to be taken to the work—always assuming that there is an A.C. supply within reasonable distance. When there is no A.C. supply available, the layout is quite similar to that shown in Fig. 3, except that a D.C. motor generator set, either petrol or paraffin driven, is housed underneath the table in the position occupied by the rectifier.

It is important that the specimen under test should form the negative pole of the arc. The Steeloscope can be used in any position, but the collimator should point directly at the arc, being 3–6 in. away from the latter. The instrument is used for detection as follows: Set up the instrument as previously mentioned, the eyepiece being in the position for the element sought; form the arc between the specimen and iron rod by bringing it in contact for an instant and separating by a few millimetres. On looking through the eyepiece a number of coloured lines are observed, one or more of which is not present when the above procedure is adopted, using two pure iron electrodes. It is important to remember that when two dissimilar pieces of iron or steel are arced together, contamination of both rods occurs, and consequently when the positive iron rod has been used for the detection of any number of elements with a given unknown sample, it is absolutely essential to clean up the iron rod before using with any other sample. This does not imply pickling, but rather the use of clean files, emery wheels, grindstones, etc. The instrument is supplied with a number of photographs or diagrams of the field of view; whilst these are of value when first using the instrument, it is seldom that an operator, once properly trained, has need to refer to them, except very occasionally. After a few days' experience with known samples the operator will learn once and for all the appearance of the spectrum lines due to each metal: in simple language, once the general view of the countryside is known by heart, particular objects are picked out with ease. Table I gives details concerning the lines used for the detection of some of the elements.

TABLE I.
WAVE LENGTHS OF LINES USED FOR DETECTION OF ELEMENTS BY THE SPEKKER STEELOSCOPE.

Element and Eyepiece Marking.		Wave lengths of Lines Used for Detection of Element in Angström Units.
Molybdenum	Mo_2	5888·3
	Mo_1	5533·0
Tungsten	W	5514·7
Copper	Cu	5218·2, 5153, and 5106
Nickel	Ni	5081·1 and 5080·5
Cadmium	Cd	5085·8
Cobalt	Co	4840·3 and 4867·9
Manganese	Mn_1	4823·6 and 4783·5
	Mn_2	4709·7
Titanium	Ti	4536·0, 4535·9, 4535·6, and 4534·8
Vanadium	V	4408·2, 4407·6, and 4406·7
Chromium	Cr_1	4289·7, 4274·8, and 4254·3
	Cr_2	5409·8
Columbium*	Cb	4059

* Not included normally on instrument.

It will be obvious from the above table that only the most distinctive line or lines for each particular element with reference to its position relative to the iron lines of the spectrum is used for detection.

Fig. 4.—Map showing the field of view for tungsten.

By way of illustration as regards distinctive spectrum lines, one of the standard maps—in this instance the tungsten map—shown in Fig. 4 is included. A brief description may be of assistance here. All the lines shown on the map, other than that labelled "Tungsten," are characteristic iron lines, and these always appear in the same position relative to one another. Using the Steeloscope as previously described, with the eyepiece set on the marking W, and using two pure iron electrodes, all these lines will be seen clearly. Looking centrally down the eyepiece, the main characteristics which are immediately apparent are two distinct triplets, one being off-centre to the left and the other off-centre to the right. If a tungsten-bearing steel is now interchanged with the previous pure iron negative electrode and the arc struck, a very distinct full line appears on the right-hand side of the left-hand triplet, as shown in Fig. 4, except that here the tungsten line is left as a half-line to facilitate distinction. Whilst this photograph is representative of the area under consideration, it does not include a number of very faint iron lines which may be seen between the two characteristic iron triplets. These are of very low intensity, and do not interfere in any way with the detection of tungsten.

The Spekker Steeloscope is essentially an accurate instrument for qualitative analysis, but it is possible, after experience, to place a rough quantitative value for certain elements. By means of a goodly supply of steels of known composition—which are supplied with the Steeloscope—it is possible by a comparison of line intensities to place a rough estimate on the quantitative value of certain elements. Table II gives some idea of the discrimination possible with the instrument. It should, however, be borne in mind that an operator working on a particular class of steels—for example, nickel-chromium-molybdenum type—soon becomes expert with regard to the metals in this class, and with his own known samples is able to differentiate between far closer limits than those given in the following table.

TABLE II.

Metal and Setting.	Results.
Tungsten (W)	Descrimination was made successfully between steels containing 16%, 5·86%, 4%, and 0·42% of tungsten. The difference between the 5·86% and 4·0% samples was small. The arc current should not be less than 5 amps.
Molybdenum Mo_1 and Mo_2.	Discrimination was made successfully between steels containing 7·3%, 2·25%, 1·0%, and 0·57% of Mo. The setting on the eyepiece Mo_2 enables percentages above 1% to be discriminated
Chromium (Cr_1 and Cr_2.	Cr_1 is used for the detection of Cr; is in the violet portion of the spectrum and is extremely delicate—percentage as low as 0·05%, Cr beng detected with ease. Cr_2 is in the green portion of the spectrum for Cr above 0·5%. Discrimination was made successfully between 18%, 12%, 6%, 3%, and 1% Cr.
Copper (Cu)	The detection of Cu is not difficult, but estimations to date have been confined to the narrow range 0·14-0·20%, where discrimination is difficult.
Nickel (Ni).....	The detection of Ni as a doublet in the green portion of the spectrum is comparatively easy under proper working conditions. Discrimination has been made between 22%, 18%, 8% and 3% Ni. Detection of traces of Ni is difficult.
Cadmium (Cd)....	Detection is easy, but no quantitative work has been carried out.
Cobalt (Co)	Discrimination was successfully made between steels containing 20%, 6%, 3%, and 2·5% Co.
Manganese (Mn_1 and Mn_2.	Mn_1 is used for detection and rough quantitative measurements up to 0·6% Mn. Mn_2—this setting is for Mn above 0·6%; discrimination between 0·6% and 1·5% can be made.
Titanium (Ti)	Discrimination was made successfully between 1·9%, 0·64%, and 0·17% Ti steels.
Tin (Sn)	Detection of Sn is easy, but no work on discrimination has been done.
Vanadium (V) ...	Detection is very easy; discrimination was made successfully between steels containing 1·4%, 0·87%, 0·24% and 0·19% V. The group of lines selected in the instrument will detect less than 0·1% V.

It may be of interest to cite a number of examples of the use of the Steeloscope in industry. These are taken purely at random, and do not by any means cover every use of this instrument :—

(1) Rapid differentiation between straight carbon steels and nitriding steels; this occurred when the parts in question were finish-machined and it was not found possible to nitride them successfully.

(2) Classification of nine steels. This was done with ease within 30 mins. These varied from mild steel up to Stellite.

(3) Rapid differentiation between standard 18/4/1 high-speed steel and substitute "66."

(4) Rapid identification of plating—zinc, cadmium, nickel, chromium and tin.

Sufficient details regarding this instrument have been given to show that it lends itself to rapid qualitative analysis of ferrous materials, being accurate, speedy, portable and very positive.

Qualitative Analysis by the use of the Spekker Photoelectric Absorptiometer.

The rapid advances made in the metallurgical industry have thrown an increased volume of work upon laboratories where old and well-tried methods of quantitative analysis were frequently unable to cope with the situation, due largely to lack of staff and the length of time required to produce the results. This situation, which is more acute at the present time than ever before, has been partly relieved by the rapid adoption of spectrographic methods of analysis. The scope of such instruments is increasing rapidly, but whilst results are of a high order of accuracy and are produced with no little speed, the installation of a complete spectrographic outfit is somewhat costly. This means that quite a number of firms cannot give serious consideration to such methods, but it is logical to assume that since a speed-up in analysis has been achieved by the application of the physical principles of the spectrograph, other well-known physical principles may do likewise. It is significant that at the present time the application of certain physical methods has materially reduced the time taken in metallurgical analyses, without in any way reducing accuracy. One or two examples may illustrate this point.

Polarographic methods of chemical analysis, originally developed by J. Heyrovsky, using the application of electrolysis with a dropping mercury electrode, are now standard in quite a number of industrial laboratories. It is not claimed that this instrument can solve every problem in analysis, but in certain cases—for example, the determination of antimony and zinc in aluminium alloys, which are reputedly difficult and lengthy by standard chemical methods—considerable time is saved without any sacrifice in accuracy.

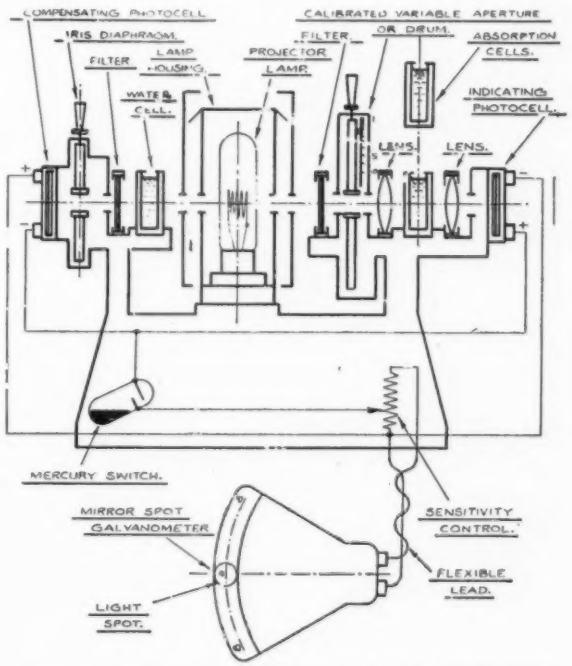


Fig. 5.—Diagrammatic layout of the Absorptiometer.

The application of coloured solutions for the estimation of certain constituents has been used for many years, as, for example, the estimation of ammonia in water by the Nessler reagent. This and like methods, however, have been limited to small amounts of constituents owing to the difficulties associated with the measurement of colour intensity by the unaided human eye. Various instruments—termed colorimeters—have been produced which assisted the human eye, but these all suffered from the same defect—namely, that the measurement of colour was arbitary and dependent upon the use of standard solutions. Within the last few years, however, there have been a number of instruments placed on the market which, whilst of varied design, adopted the same principle—namely, the estimation of the amount of light transmitted by a coloured solution. It is not the purpose of this article to discuss the merits of numerous instruments, but rather to confine attention exclusively to what has proved to be a sound and reliable one—namely, the Spekker Photoelectric Absorptiometer—

which is the only instrument of its type produced exclusively in this country. This instrument and its uses will now be described in detail.

Fig. 5 shows diagrammatically the essential details of the absorptiometer. In the centre is a tungsten filament 100-watt projector lamp enclosed in a lamphouse provided with apertures to left and right. On the right-hand side the light passes through a colour filter, a calibrated variable aperture, a lens, through a glass cell containing a solution, a further lens, and finally falls on to a photocell. On the left-hand side the light passes through a glass cell containing distilled water, a colour filter of the same colour and density as that used on the right-hand side, a variable aperture—iris diaphragm—and finally on to another photocell. The photocells are connected electrically in opposition, as shown in Fig. 5, across a mirror spot galvanometer. A variable resistance, shown in the diagram as a sensitivity control, and a mercury switch are included in the circuit. The instrument is operated in the following manner: All adjustable apertures are closed, and all switches turned off. The light source in the mirror spot galvanometer is switched on and water cells are placed on either side of the lamp in the positions indicated. The calibrated aperture or drum is set, for example, at 1·00, and suitable colour filters appropriate for the solution being tested are inserted in the position shown. The light source is switched on, the galvanometer key depressed, and the sensitivity control

Fig. 6.—View of Absorptiometer and accessories in case.

adjusted to give maximum deflection on the galvanometer. The variable aperture on the left-hand side and in front of the left-hand photocell—termed the compensating photocell—is opened to give a null reading on the galvanometer. Under these conditions equal quantities of light are being transmitted to each photocell and the photoelectric currents produced are balanced. The lamp is now switched off. The coloured solution to be tested is now placed in the cell-holder—see Fig. 6—in an adjacent position to the water cell on the right-hand side of the instrument, and the cell-holder is moved so that this coloured solution is in the path of the rays of light. The light source is again switched on and the galvanometer key depressed: a deflection is shown on the galvanometer due to absorption of some of the light in passing through this solution. The drum is opened to allow more light to pass through, until the photo-electric currents are again balanced. The reading on the drum is now, for example, 0·73, and this value—subtracted from the initial setting of 1·00 to give a value of 0·27—is an empirical measure of the amount of light absorbed by the solution. This reading of 0·27 is of no significance until it is correlated with a graph prepared from solutions containing definite amounts of the same constituent; such a graph shows the relationship between drum reading and concentration of the constituent element concerned.

Fig. 6 shows a photograph of the complete absorptiometer, housed in a wooden box, and containing galvanometer, glass cell-racks, and a rack for coloured filters. This layout has been found from practice to be entirely satisfactory, and readings can be taken with the greatest of ease and a minimum of delay. Briefly, the instrument can be used for the measurement of absorption of light of any solution; it may thus be applied to the estimation of an element which produces a colour proportional to its concentration. The instrument for metallurgical work is normally supplied with a set of nine pairs of colour filters, one pair termed heat-absorbing filters which can be used throughout all estimations to protect the photocells, and the other eight pairs ranging from red to violet. It is essential when using this instrument, in order to obtain high accuracy, to choose the appropriate pair of filters, so that the light used in measurement is from that part of the spectrum which is absorbed by the solution being measured.

The following table will be found of general assistance, although it is not possible to lay down hard-and-fast rules in this connection.

TABLE III.

Filter No.	Colour of Filter.	Coloured Solutions Obtained.	Approximate Wave-length of Band of Light Transmitted by Filter.
601	Violet	Yellow, yellow-orange, golden	4,000–4,700 Å
602	Blue	Orange, yellow-orange	4,500–4,900 „
603	Blue-green	Orange-red, red	4,800–5,100 „
604	Green	Orange-red, red, violet	5,000–5,400 „
605	Yellow-green	Violet, purple	5,350–5,750 „
606	Yellow	Blue, bluish-purple	5,600–6,100 „
607	Orange	Blue	5,800–6,500 „
608	Red	Blue	6,500–7,000 „

The absorptiometer is also normally supplied with three sizes of glass cell, of internal width 1 cm., 2 cms., and 4 cms.; this selection of cells enables reading to be taken over a fairly wide range of colour intensity. By way of illustration, the following complete estimation of manganese in alloy steels is given, as bringing out the essential manipulative details relating to the instrument proper. It is perhaps as well to make one point quite clear at this stage. The absorptiometer readings may quite well be taken by a semi-skilled operator, but the intelligent use of the instrument as applied to metallurgical analysis in general is the work of a skilled chemist. In this respect the instrument differs from the Steeloscope mentioned earlier in his article.

0·5 grm. of the alloy steel in the form of turnings, millings filings, etc., is dissolved in 25–30 ml. of a sulphuric-phosphoric acid mixture (15% sulphuric acid, 15% phosphoric acid); it is then warmed to dissolve and oxidised with 5 ml. of 1·20 s.g. nitric acid. If necessary, it is fumed to dissolve carbides, and the solution is then made up to about 50 ml. volume with distilled water. 10 ml. of 2% silver nitrate solution and 1·5 grm. of pure ammonium persulphate is added. Boil until evolution of oxygen ceases, then cool. Add *circa* 0·5 grm. urea and make up to 100 ml. with distilled water. Wash out a 1 cm. glass cell with this solution and then fill up and measure the absorption on the instrument, using Filters 604—spectrum green. This gives a reading of permanganate due to manganese, together with any other coloured salts in solution. The cell is emptied, and one drop of a 1% sodium nitrite solution added and the cell again filled. The addition of sodium nitrite completely decolourises the permanganate without affecting the other coloured solutions present. The absorption of this solution is measured, using the same filters and settings. This latter reading gives the absorption due to other coloured salts in solution, such as nickel, chromium, molybdenum and like elements. The difference between the two absorption readings so obtained is due to manganese as permanganate. This reading, referred directly to the calibration graph for manganese, gives the percentage of the latter element in the steel under examination. This method, which is simple to operate, using few reagents and no filtrations, is applicable for the estimation of manganese in any steel. With one filtration for the removal of graphite, the method is applicable to ordinary and alloy cast irons.

(*Continued on page* 148.)

METALLURGIA
THE BRITISH JOURNAL OF METALS.
INCORPORATING "THE METALLURGICAL ENGINEER"

What Britain is Doing !

DURING times of crisis, and there have been many since Britain, for the sake of pledges and ideals, dared withstand the aggressions of the mightiest military Power in history, some people persist in asking the question : What is Britain doing ? They do not expect to be answered, because the question is asked in such a way that indicates discouragement and sometimes derision. Its seems to be entirely overlooked that Germany was building up and perfecting her schemes for world domination many years before the actual outbreak of hostilities ; she organised her forces for rapid movement, and equipped them to take advantage of the new technique she had developed. To accomplish this the whole industry of Germany was mobilised and harnessed to her fighting machine. In comparison, Britain had done relatively little to organise and mobilise industry to combat the resources of mechanical power then in the hands of Germany.

Some people experience an uneasy feeling regarding the effectiveness of Britain's industrial organisation to adjust itself to the conditions imposed by war, but the fact that the British forces were inadequately equipped to meet the new war technique developed by Germany was not due to any failure on the part of British industry. Obviously, to transform industry from peace to a war footing, when war has been declared, is not easy, and the difficulties are greatly increased because a condition of emergency then exists, and the organisation of industry is governed largely by the immediate needs of the Forces rather than to meet the requirements of a comprehensive scheme to equip the Forces in the light of modern mechanised technique. The fact that industry has been forced to meet emergencies has delayed complete organisation for total war requirements, and while there is cause for criticism, we should be honest and admit there is cause for pride. On the whole, the tremendous amount of work accomplished since the war began is evidence that the determination displayed by the various fighting forces is shared by the vast majority in industry ; they are meeting and overcoming numerous difficulties.

It must be remembered that Britain and the Empire have resisted aggression from the opening days of the war, and have fought to win that breathing space which has helped to prevent the destruction of civilisation, and this has been accomplished against the greatest military Power in history. Considering the magnitude of the task Britain undertook, it is a marvel that we continue to gain strength, and every day's resistance helps to turn the tide in our favour. It is true we have been forced to retreat, and this fact has saddened and disheartened many people, but every retreat has been a step backward to gain time, a step toward ultimate superiority, a step towards final victory. That famous American foreign correspondent, Allan A. Michie,* says of the British : "Almost any army can be good when the odds are in its favour and it is forging ahead, but it takes the kind of plain guts the British have to withdraw as well as they did from the death-traps at Dunkirk, Greece, Crete, Malaya and Burma. . . . Out-numbered and out-equipped, the British forces knew their chance of living was small, but they fought and died so that those who came after them would have a chance. They gave their lives so that the Empire could gain the time necessary to put an end to retreats." This is the opinion of a man who watched our troops land at Alexandria after they had been bombed incessantly for twelve days in the evacuation of Crete, and who saw our troops at Singapore and Malaya a few days before they were to begin their hopeless fight.

These delaying retreats, discouraging on the surface, are now as much a part of the global war strategy of the United Nations as the counter-offensives which will later bring us victory, but we must make use of the time they have and are giving. The fact that little information is leaking out on what is being done in this country does not mean that nothing is being done or that responsible people view with complacency the progress so far made towards parity with the enemy in men and equipment. Not only have we fought on many fronts, but we are sacrificing men and ships to send supplies of tanks, aeroplanes and other war material to Russia, and there is need for even greater efforts in supplying the arms and equipment which continue to be needed in ever-growing quantities.

There is a tendency to under-rate much that has been done, but there can be few who have any knowledge of aeroplane design and construction who will fail to appreciate the significance of the report on German and Italian aircraft engines and airframe parts, a summary of which is commenced elsewhere in this issue. This metallurgical study, prepared by the Aero Steel Components Sub-Committee of the Technical Advisory Committee to the Special and Alloy Steel Committee, can be regarded as an example of work done and in progress, the importance of which cannot be overestimated.

The principal object of these investigations was to obtain data on the types and quality of materials used, methods of manufacture, efficiency of the heat-treatment to which the parts had been submitted, together with any other information which might prove of value, as, for example, details of the finish. Further, the influence of restrictions due to our blockade on enemy procedure and selection of materials was kept in mind. Attention was given chiefly to engine parts, but a number of airframe and miscellaneous components were included. The present issue describes briefly the engines and gives data on crankshafts ; succeeding issues will include sections on connecting rods, gudgeon and wrist pins, cylinders and cylinder liners, valves and valve springs, gearwheels, camshafts and other shafts, steel castings, bearings and miscellaneous engine parts. Two sections will be devoted to airframe components, and a concluding section will give a tabulated summary of all parts.

These investigations have been in progress since the early days of the war. The parts examined represent an extensive range of the various types of enemy aircraft which have fallen into the hands of the R.A.F. since the beginning of the war. It would not be policy to attempt to make detailed comparisons between these parts and parts from corresponding types of British planes, but amongst those whose knowledge and experience enables a reliable

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "Metallurgia" should not be taken as an indication that they are necessarily available for export.

* Author of "Retreat to Victory."

authoritative opinion, there is a feeling of confidence that in many important respects British planes are superior to those of the enemy.

While this example indicates the thoroughness in which British industry is striving to excel the enemy in efficiency, and to ensure that the materials used in our offensive and defensive weapons and equipment are superior to those of our enemies, it should not be forgotten that the whole industry of Germany is mobilised and harnessed to her fighting machine, and every ounce of energy, coupled with superior skill, must be applied to pave the way to victory.

To achieve this, it is not enough to ask, "What is Britain doing?" but rather to ask, "What am I doing?"

New British Chemical Standards

BUREAU of Analysed Samples Ltd., whose war-time address is at Markington, Harrogate, announces two new British Chemical Standards steels, viz. :—

13% CHROMIUM STEEL, No. 211.		0·3% LEAD STEEL, No. 212.	
Chromium	13·81	Lead	0·28
Carbon	0·247	Carbon	0·415
Silicon	0·29	Silicon	0·13
Sulphur	0·010	Sulphur	0·023
Phosphorus	0·017	Phosphorus	0·054
Manganese	0·34	Manganese	0·73

Each sample has been analysed for minor elements such as As, Ni, Cr, Cu, V, Ti and Co.

The 13% Cr steel, No. 211, will serve as an analytical standard for the "straight" chromium type of rustless steel, whereas the 0·3% Pb steel, No. 212, is a Ledloy free-cutting steel, and is useful as an analytical standard for the determination of lead in steel. Where possible, the methods for Pb, S and P recommended by the Iron and Steel Institute Sub-Committee on Standard Methods of Analysis have been used. Eight or nine different chemists, representing independent analysts, government departments, manufacturers and users of these grades of steel, have taken part in the analytical standardisation.

Fuller details will be found in the latest list, No. 315, which is just being issued.

Supplies may be obtained from any laboratory furnisher or direct from Bureau of Analysed Samples, Ltd.

Economy in Tin Consumption

BOTH in the United States and in Great Britain every use of tin has been scrutinised by groups of experts, some uses have already been eliminated and substantial reductions in current consumption have been effected thereby. The controlling authorities are planning not a flat percentage reduction, but are demanding the intelligent co-operation of every user, so as to secure the greatest economies compatible with the least reduction in their contribution to the war effort.

Very great reductions in the tin used for tinplate are being effected by restrictions on its use, which, in spite of the disadvantages, are accepted in present conditions. A substantial economy is the use of light electro-deposited tin coatings, a subject on which a special article is published elsewhere in this issue. While electro-deposited tin coatings serve the immediate purpose of saving tin, they will ultimately find new markets and widen considerably the use of tin-coated steel.

Owing to the time lag between the date at which important economies take effect, and the time at which supplies from the East were cut off, the tin stocks of the United Nations must already have been somewhat depleted, and the adoption of measures of economy becomes every day more urgent. In this connection it is noteworthy that the current issue of *Tin and Its Uses* is devoted to emergency economies in tin. It is shown that a cut of 50% in our tin consumption can be effected, and the zeal and skill of our technicians can surely find no better outlet than in abandoning tradition and superfluous factors of safety, and for the period of the war in devoting an extra quota of care and judgment to the most economic use of our limited supplies of tin.

Tin and Its Uses is obtainable gratis from the Tin Research Institute, Fraser Road, Greenford, Middlesex, or in the United States from the Batelle Memorial Institute, 505, King Avenue, Columbus, Ohio.

A "Cold-Process" Degreasant

DEGREASING is a term covering a wide range of requirements from cleaning dirty machinery up to producing chemically clean surfaces for critical finishing operations. It includes all forms of unsaponified grease and oil, and most of the compounds containing various waxes. Oil may be applied to reduce friction between moving parts, or to protect certain metals from rusting during fabrication; but very searching methods have to be introduced when it is required to remove oil completely from metal surfaces in order to subject them to finishing processes.

Many methods are employed to degrease and clean parts, such as the use of clean, dry sawdust, burning off, the use of a hot caustic-soda bath, and various other types of chemical solvents. With the exception of a few methods, like cleaning with sawdust, the use of which is now practically confined to certain aluminium products, heat is necessary, and the operation is usually costly.

Many attempts have been made to discover a degreasant which would successfully overcome degreasing problems by direct application and without the use of heat. Such a degreasant has recently been marketed under the trade-name of "Gunk," by Charles Mack and Co., Old Colony House, Ridgefield, Manchester, 3, which satisfactorily converts all mineral oils, greases and petroleum jellies into a water-soluble state. This material is antiseptic, non-caustic, non-corrosive and non-inflammable. It works cold, and is manufactured ready for use. The articles to be treated are dipped or simply brushed or sprayed with the compound, and subsequently rinsed in cold water. The material has no chemical reaction on aluminium, chromium or other metals; in addition it will not affect cellulose, enamels, varnish or paintwork. Gunk products are available in three forms—"Gunk D.P. Solution," "Gunk Aircraft Compound 901," and "Tarlena Tar Solvent." We have tried the first of these with such satisfactory results that we feel justified in saying that these products will repay investigation with a view to their application in the many phases of degreasing and cleaning necessary in present-day production.

Non-Ferrous Metals Campaign

NEW bulletin-posters, which emphasise the importance of non-ferrous metals in the production of tanks, ammunition, aircraft and ships, have just been issued. They are the first "shot" in a campaign designed at the suggestion and with the active co-operation of the Non-Ferrous Metals Control to impress upon those engaged in the industry the vital importance of non-ferrous metals in war production. Each bulletin carries a photographic enlargement of some aspect of the war, and emphasises action; further bulletins will be issued from time to time based on current war news. Each bulletin describes briefly how brass, copper, zinc and zinc alloy die-castings are being applied in different sections of the battle, and indicates the influence of everyone engaged on the production of these materials in helping the men at the battle front, in maintaining the sea lanes for our ships and safeguarding supplies of food and materials. These are a really good effort, and as they are being distributed in selected works many readers will have the opportunity of appreciating the importance of this aspect of production.

The Basic Open-Hearth Process To-day

Part I.—The Modern Basic Open-Hearth Furnace

By W. Geary

This is the first of a series of articles on modern basic open-hearth furnace practice, in which the author briefly outlines developments in the open-hearth furnace from the application of Siemens' regenerative principle to the present time. Types and sizes of furnaces are briefly discussed and constructional details are considered, particular attention being given to ports, roofs, linings, and to the regenerators.

IT would be difficult to contemplate the evolution of the modern open-hearth furnace without taking a glance back to the earliest days. One is impressed by the realisation that practically the whole of the great development of both the furnace and its function has taken place during the lifetime of men who are still associated with it. The progress that has been made is the more remarkable when it is remembered that it has all been in the nature of improvement or development, rather than of revolution. For the fundamental principle of heat regeneration, demonstrated by Siemens in 1856, is still the one factor essential to the operation of the process.

The Siemens' invention related to the regeneration of heat and the production of higher temperatures in furnaces used in the glass and ceramic industries. The connection with metallurgy was made by the brothers Martin, who were operating puddling furnaces. They saw the possibility of providing their furnaces with a much higher temperature than had been attainable by burning solid fuel with cold air. Application of Siemens' principle enabled iron to be rendered fluid enough in the furnace to allow the slaggy inclusions to separate. From there it was but a short step to making steel to specification by the addition of molten pig to pure iron, and to the melting of a proportion of wrought-iron scrap (then a serious encumbrance on the market) in a hearth furnace. The story of these developments has long been in the students' textbooks; and a most lively and imaginative account has recently been written by S. F. Perin.[1] In this paper he says, "The open-hearth furnace is a marvellous example of unexpected and immediate progress realised by the collaboration of two techniques—metallurgy and heat."

Since the inception there have been no more "unexpected and immediate" advances; yet the accomplished progress depended, and progress to-day depends largely upon the ability of furnace operators and technicians to utilise the results of workers in allied scientific and technical fields.

Furnace Sizes

The first furnaces to work the open-hearth process in 1866 were of 1½ to 2 tons capacity, and the demonstrated success of the process in 1867 resulted in a quickened interest in France, England and the U.S.A. New furnaces were built, usually of greater capacity. The United States set the pace with size: they reached 35 tons in 1887, 50 tons in 1892, and 75 tons in 1899.

Until about 1880 all open-hearth furnaces worked with acid bottoms, but from then the basic process made rapid strides. Small basic furnaces were at that time built in France and the Ruhr; while five 20-ton basic furnaces were built in England in 1885, and the first basic furnace, of 15 tons capacity, in the U.S.A. in 1886. In the U.S.A. in 1890 the first basic tilting furnaces were built, with a capacity of 50 tons.

On the Continent, the development of size was slower. In 1890 Witkowitz built 20-ton furnaces that were not enlarged until 1900. In the Ruhr the usual capacity in the years 1913-1924 was 30–35 tons.

British practice was between these two. Our iron and steel industry was largely developing upon sites already in operation; and although opportunity was seized to incorporate new types of furnaces in larger sizes whenever new sites were developed, much of the advance achieved was a result of alteration and improvement of exsting plant.

Rapid progress was made in the years following the last war. The usual size of furnace in the nineteen-twenties was 30–40 tons on the Continent, 45–65 tons in England, and 50–100 tons in the United States. Tilting furnaces were in use from 90–200 tons capacity.

TABLE I.
DISTRIBUTION BY SIZE OF BASIC OPEN-HEARTH FURNACES IN U.S.A., JANUARY 1, 1935.

Fixed Furnaces.				Tilting Furnaces.	
Rated Capacity per Heat, Gross Tons.	Number of Furnaces.	Rated Capacity per Heat, Gross Tons.	Number of Furnaces.	Rated Capacity per Heat, Gross Tons.	Number of Furnaces.
350	1	95	35	400	1
300	1	90	64	300	4
250	8	85	19	270	4
200	5	80	22	240	3
160	1	75	52	200	11
150	77	70	30	180	2
145	3	65	29	100	13
140	8	60	57	20	3
135	12	55	4	4½	1
130	11	50	36	—	—
128	6	45	36	—	—
125	29	40	22	—	—
120	58	36	6	—	—
118	8	35	4	—	—
115	20	30	12	—	—
112	4	27	3	—	—
110	42	20	4	—	—
105	23	15	2	—	—
100	156	3½	3	—	—

TABLE II.
DISTRIBUTION BY SIZE OF BASIC OPEN-HEARTH FURNACES IN GREAT BRITAIN, JANUARY, 1938.

Fixed Furnaces.		Tilting Furnaces.	
Rated Capacity per Heat Tons.	Number of Furnaces.	Rated Capacity per Heat Tons.	Number of Furnaces.
140	1	300	4
100	12	250	5
90	24	240	2
85	15	230	1
80	9	220	5
75	20	180	3
70	24	175	5
65	12	160	1
60	47	120–160	4
40–60	2	140	1
50–60	4	120	2
55	10	85	1
50	33	80	5
40–50	5	—	—
40	18	—	—
20	3	—	—

Table I is extracted from Mr. Reinartz's paper,[2] and Table II is compiled from data kindly supplied to the author by the British Iron and Steel Federation.

Inspection of these tables shows that the more common sizes of fixed furnaces in the United States are 100 tons, 150 tons, 90 tons, and 120 tons, in that order; and in Great Britain 60 tons, 50 tons, with 90-ton and 70-ton furnaces equal in third place.

In regard to new installations, most American operators appear to favour a furnace of 150 or 175 tons capacity[3]; a

1 S. F. Perin. *Revue Universelles des Mines*, 1939, vol. 15, June, pp. 244–252.

2 L. F. Reinartz. *Journal of the Iron and Steel Institute*, 1938, No. II, pp. 349.P *et seq.*

3 W. H. Burr. *Iron and Steel Engineer*, 1942, vol. 19, Jan., pp. 26–50.

new plant in the Chicago district is building 150-ton furnaces. The most recently built furnaces in Great Britain are 85 or 90-tonners. The very large fixed furnaces in America will no doubt continue in use for special purposes as will the small furnaces in this country, but the tendency for general purpose furnaces in America is towards about 160 tons, and in this country to about 90 tons.

The existence of the large fixed furnaces in America is perhaps accounted for by a comparative deficiency in large tilting furnace capacity in comparison with Great Britain. Using the figures of Tables I and II to determine the potential output per charge of all available furnaces, the following result is found (Table III).

TABLE III.
POTENTIAL OUTPUT PER CHARGE OF ALL FURNACES.

	Potential Output.		Ratio.	
	Tilting Furnaces, Tons.	Fixed Furnaces, Tons.	Tilting Furnace Capacity.	Fixed Furnace Capacity.
United States	7,324	86,847	1	11·9
Great Britain	7,290	15,800	1	2·2

It thus appears that the industry in Great Britain prefers to use tilting furnaces for a greater proportion of (mainly) tonnage steels. This feature is probably due to the British steel industry having been based, to a greater extent than the American industry, on the use of hot metal.

It may well be that any large scale increase in furnace sizes will take place only with tilting furnaces. The author has had some experience with tilting furnaces, and holds the view that the useful economic limit of size has not yet been reached. No one who is responsible to-day for initiating the construction of tilting furnaces hesitates to order a 300-ton furnace. It has become a conventional size. A 400-ton tilter exists in the United States, and a second is being built, while in Russia a tilting furnace designed to take charges of 400–500 tons is in operation.[4]

Nominal Capacity and Weight of Heat

Although the nominal or rated capacity of a furnace gives a guide to its size, it does not always give an accurate measure of the weight of steel tapped per heat. The Open Hearth Committee of the British Iron and Steel Industrial Research Council, in their paper, "British Open-hearth Data and Their Correlation,"[5] said: "The definition of furnace capacity is a matter of some difficulty. It is well known that furnaces said to be of a certain nominal capacity (which was probably strictly correct when they were first built) are producing—as a result of deepening the bath and widening the hearth—considerably more per heat than their rated capacity. For the purposes of this inquiry, capacity has been regarded as the tapping capacity, calculated from the tons of ingots made per heat and the percentage yield of ingots, the figure therefore being the weight of metallic charge (including iron from the oxide used) per heat." They therefore made use in their paper of three figures of capacity—namely, nominal capacity, tons per cast, and tapping capacity.

The extent to which these three measures can vary is shown by the following average of data, relating to five fixed basic cold-metal furnaces quoted in the above paper:

	Tons.
Nominal capacity	60
Tons per cast	80
Tapping capacity	87·4

The wide divergence thus shown between nominal capacity and the size of the heat tapped is undoubtedly due mainly to alterations made to furnaces, principally to their upper structure.

Most older furnaces of conventional design lent themselves to such alteration, but there is not the same latitude in furnaces of more modern, or of special design. Tilting furnaces fall into the latter category. Table IV, relating to eight basic tilting furnaces,[5] shows that the tons per cast is in general rather less than the nominal capacity:—

TABLE IV.
EIGHT BRITISH BASIC TILTING FURNACES.

Nominal Capacity.	Tons per Cast.	Tapping Capacity.
120	114	121·2
140	125	133·0
150	130	138·3
160	130	138·3
150–175	160·3	171·2
250	236	251·0
240	240	268·6
300	253	269·0

In some cases this difference between tilting furnaces and fixed furnaces may be due to the fact that the building of the tilter was an alteration of an existing structure, and that a new nominal capacity was given to the reconstructed unit.

The influence of the tapping capacity of a furnace on its rate of output is shown graphically in Fig. 1.[5]

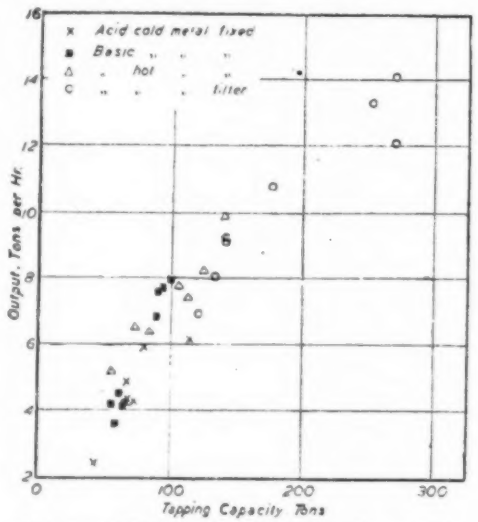


Fig. 1.—Influence of tapping capacity on rate of output.

Bath Dimensions

A study of published information reveals a wide variation in the relation existing between bath dimensions (particularly bath area) and the tapping capacity of a furnace. Tilting furnaces, owing to their deep baths, fall into a class by themselves. The figures relating to fixed furnaces show some very interesting variations. In eight hot-metal furnaces[5] the bath area in square feet per ton capacity varies from 2·77 to 6·16, while the output in tons per hour per 100 tons capacity varies only from 6·65 to 9·50. The average bath depth in inches varies from 9·96 to 22·15.

These big variations are largely the result of alterations made to furnaces with a view to increasing output and decreasing cost. The author in 1937 described such an alteration.[6] The furnace was originally built to tap 60 tons. Its maximum output was 983 tons per week. Without structural alteration, the size of the charge was increased to 75 tons, at which capacity its maximum output became 1,244 tons. A structural alteration was then undertaken: the bath was lengthened and a water-cooled gas port was installed, a semi-sloped backwall was built, and the level of the foreplate was raised. The enlarged furnace made 1,838 tons in its best week. This alteration is typical of scores that have been made throughout the world. Such alterations, although bringing a good deal of confusion to the statistics of furnace design, have played a great part in the progress that has been made in the industry.

Merely increasing the charge weight in a given furnace usually results in an increased output. Experience in the United States shows that the percentage increase of production from larger heats is at least equal to half the

4 A. Bulavkin and V. Kiselev, *Stal*, 1940, No. 4, pp. 15–16.
5 "Symposium on Steelmaking." Iron and Steel Institute, Special Report No. 22.
6 W. Geary. *Journal of the Iron and Steel Institute*, 1937, No. II, p. 261P.

percentage increase in the size of heat tapped.[7] This has been in general the author's experience, but he believes it is not a rule that can be applied indiscriminately and indefinitely; there will come a point in a given furnace when an increased charge weight will result in a lowered output. The determination of the optimum weight can be done only by experiment and observation.

The bath depth largely influences the output per unit of hearth area, as is shown in Fig. 2.[5] It will be noticed that in hot metal furnaces the rate of increase of output per unit of hearth area is less than in cold metal furnaces: bath reactions play a much bigger part in hot than in cold metal furnaces. A conclusion that may be drawn from this is that the full advantage cannot be obtained from an enlarged (and deepened) furnace unless a suitable burden, of low metallurgical load, can be provided for it. The relationship between bath area and output is shown in Fig. 3.[5]

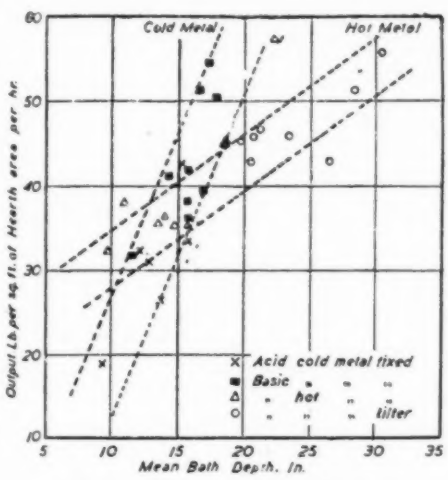


Fig. 2.—Influence of bath depth on output per unit area.

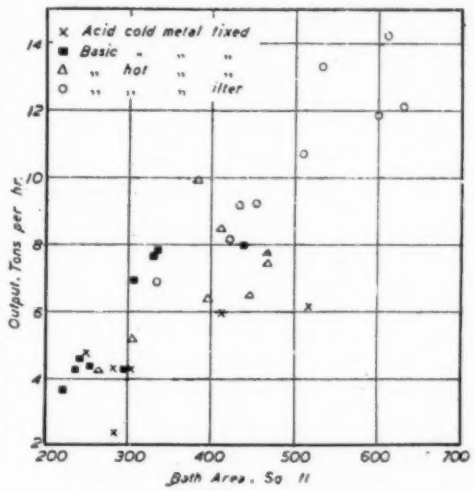


Fig. 3.—Relation between bath area and output.

It is clear from the foregoing that considerable latitude is permissible in bath dimensions, both of surface area and of depth. Both shallow and deep baths have their advocates. Depths vary from about 1 ft. to about 4 ft. The protagonist of the shallow bath claims, rightly, that the large slag-metal interface permits rapid reactions; he claims also that it allows closer control of the finishing point. The advocate of the deep bath disputes that latter contention: he claims that the rather slower reactions in the deep bath allow time to establish and maintain his finishing point with more certainty, and that he produces more steel, of equal quality, per unit of time.

Block Design

No other part of the open-hearth furnace has been so subject to experiment as the block. The block has to perform two separate functions that are reconcilable to only a limited extent. It must have gas and air ports to give such direction, velocity and volume to the streams as will ensure proper combustion of the mixture; yet these same ports on reversal, must be passages adequate for the evacuation of the products of combustion without promoting high velocities leading, among other troubles, to unduly rapid erosion of the structure.

Years devoted to the study of block design have resulted in the evolution of many ingenious designs and devices. Some designs were made to meet special conditions—e.g., oil or coke-oven gas firing; still more were made on producer gas furnaces in an attempt to improve either the incoming end or the outgoing end or both. The result of all the effort has been of great value to the industry as a whole.

Much knowledge concerning combustion and the flow of gases has been acquired from the study of the performance of furnaces of special design and of the results of fuel research work. The application of the knowledge has brought about an enormous improvement in conventional design. Thirty years ago blocks were, on the whole, not good; to-day it is most unusual to meet a bad one.

The Conventional Block

In the early open-hearth furnaces the block took the form of a mass of masonry carrying one or more gas ports beneath one or more air ports. The slope of both gas and air ports was about 1 in 3, the ports thus being substantially parallel. The relative areas of gas and air ports were often such that the incoming streams of gas and air had similar velocities. Satisfactory combustion is almost impossible under such conditions; stratification of gas and air occurs, and combustion is not completed until the gases have left the laboratory of the furnace. The available heat is thus developed, not above the bath where it would do useful work, but in the outgoing ports, downtakes and regenerators, which it rapidly destroys. It is now usual to find in the conventional block that a line through the centre of the air port makes an angle of about 18°–20° with a line through the gas port, thus allowing the air to flow down on to the gas. But more important probably than such angle of inclination of the two streams is the gas : air velocity ratio. This ratio depends on relative volumes and port areas; the Open Hearth Committee[5] found that furnace performance increases fairly rapidly up to gas : air velocity ratios of about 5. Their plotting of the relevant factors is reproduced in Fig. 4.[5]

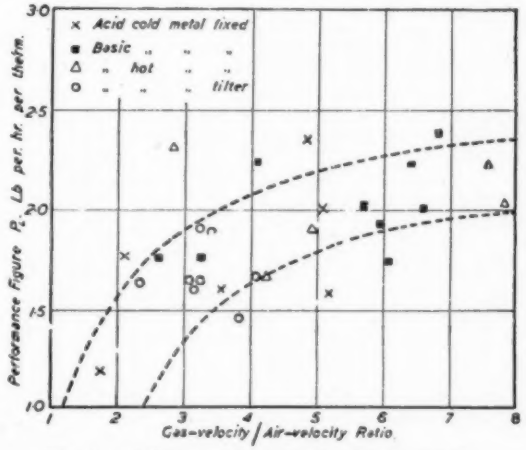


Fig. 4.—Influence of gas-air velocity ratios.

Special Block Designs

Three of the special blocks which use producer (or mixed) gas are particularly well known. All of them are designed to promote rapid combustion. Each achieves the object in its own particular way, but each applies the fundamental principles of suitable direction of the streams and suitable velocities.

1. *Venturi Furnace.*—This design is very popular, and is installed in many works throughout the world. By the

courtesy of the Lancashire Steel Corporation, Ltd., Figs. 5 and 6 are reproduced from the contribution to the Steel Symposium of Sinclair Kerr and his collaborators.[5] Fig. 5 is interesting in that it shows the type of conventional block that is being superseded.

2. *Terni Furnace.*—This design incorporates fan-driven air and a long combustion chamber between the uptake and the melting chamber. The results shown in Table V. have been reported.[8]

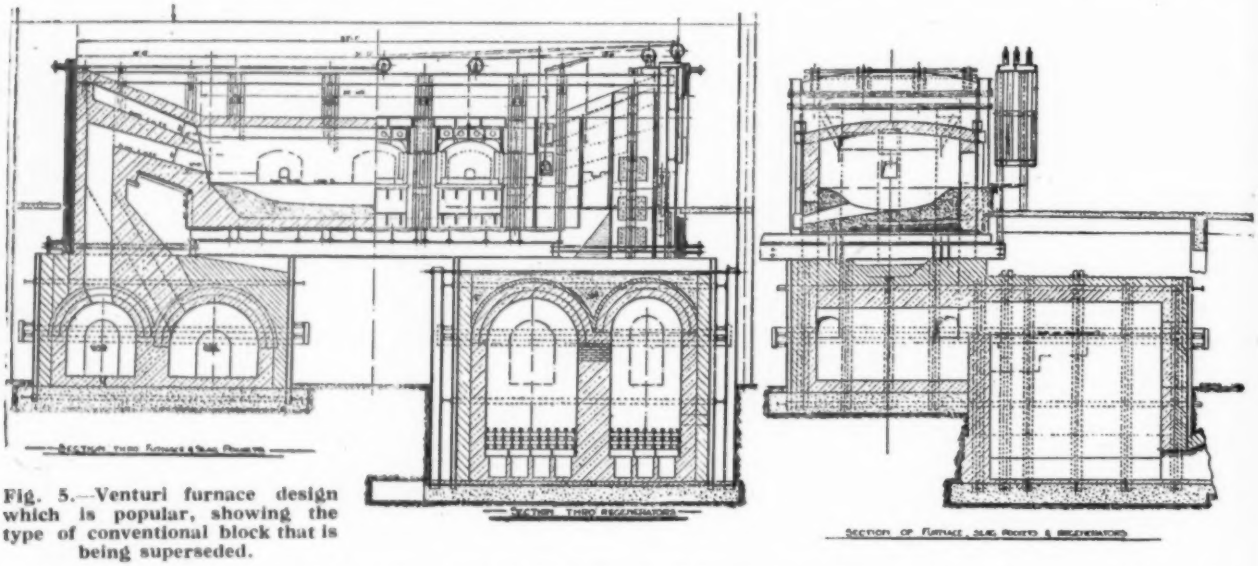


Fig. 5.—Venturi furnace design which is popular, showing the type of conventional block that is being superseded.

TABLE V.
COMPARATIVE RESULTS WITH THE TERNI PORT.

	No. of Heats.	Total Output for the Campaign, Tons.
20-ton furnace, old type	450	8,500
" " Terni type	1,000	24,000
40-ton furnace, old type	450	16,000
" " Terni type	1,000	45,000

3. *Maerz Furnace.*—This furnace is illustrated in Fig. 7. It has a short water-cooled gas port outside the end wall of the furnace, and in the ordinary sense, no block. The air is admitted through vertical uptakes at each side of the incoming gas stream, and the turbulence thereby created results in very rapid combustion.

Special blocks have been designed to burn fuels other than producer gas. Of furnaces burning cold coke-oven gas probably the best known is the Hoesch. This furnace is illustrated in Fig. 8. It has been fully described in the Steel Symposium[5] and elsewhere, and it is sufficient here to point out that the design conforms to the fundamental requirements of combustion of direction and turbulence. Twin streams of coke-oven gas are blown, at a pressure high enough to give them sufficient momentum to maintain their direction, across a rising stream of preheated air. Intimate mixture takes place, and combustion is usually completed quite early.

Block Mechanisms

The movable water-cooled gas port appears to be gathering adherents. It was described by Rose and Washburn[9] in 1930, and is reported[3] to be installed in a number of new 150-ton furnaces being built near Chicago. The furnaces are designed to burn mixed gas, which demands a fairly small port to give directional velocity to the incoming gas. Since mixed gas-firing needs a high preheat temperature for the gas, a small port is not suitable for the outgoing end, and the Rose movable port may be

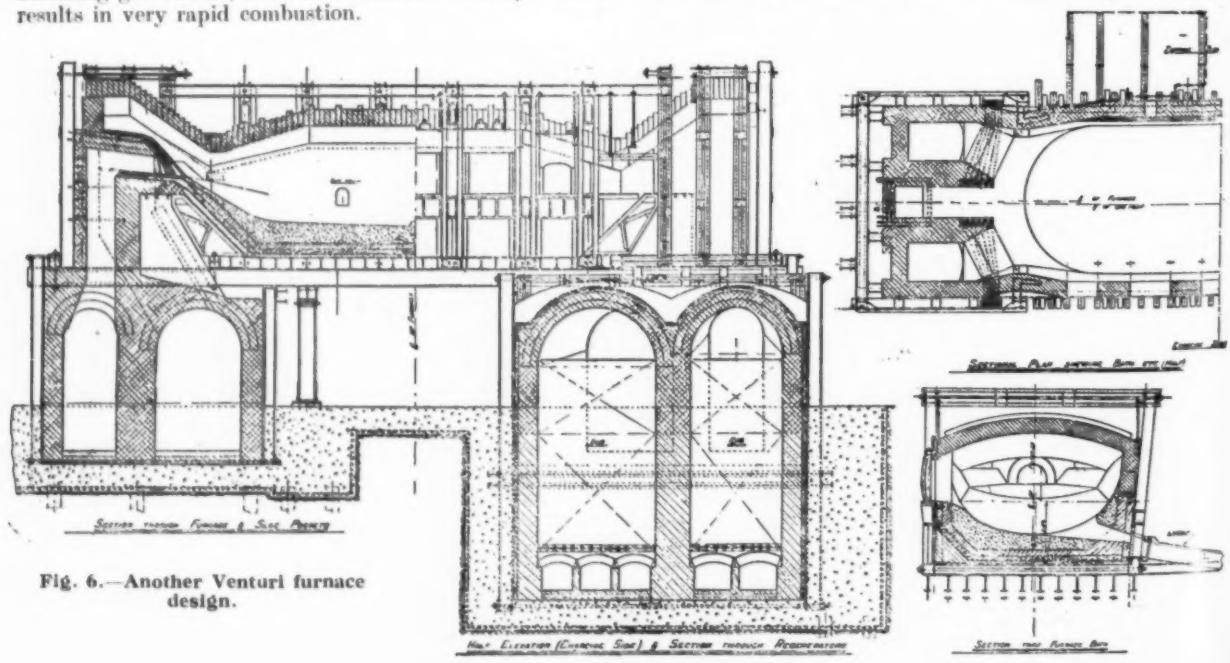


Fig. 6.—Another Venturi furnace design.

drawn back to uncover the gas uptake, thus allowing a suitable proportion of the waste gases to go through the gas regenerator.

Water-cooled Ports.—A silica brick port in a basic open-hearth furnace is subject to powerful eroding agencies : the earliest and still popular method of minimising erosion is water-cooling. Two main methods of applying the cooling are used. One is to provide a series of pipes about 1 in. in diameter, built into the brickwork, and following the contour of the arch ; the other method makes use of a tank cooler. Some operators prefer not to use water-cooling, and build their blocks of non-spalling basic bricks.

Auxiliary Uptake Dampers.—The McKune system[10] provides water-cooled dampers for adjusting the areas of the inlet and outlet ports. An interesting modification of this idea has been made at a British works on a furnace using mixed gas. A water-cooled damper caused the waste gases to by-pass the gas port, and proceed through the air port to the gas downtake. By this means the gas port was saved much erosion, and at the same time the necessary amount of heat was allowed to reach the gas regenerator.

Auxiliary Air Ports.—One British plant uses a block having an air port at each side of the gas port, as well as two above.[5]

Uptake Design.—The present tendency is to make both gas and air uptakes as large as possible. The lower velocities resulting from enlarged uptakes reduce the erosion of brickwork, bringing about savings in maintenance cost. Careful recording of the consumption of refractories in the various parts of furnaces showed that the continual weekly repairs to the uptake stoppers in the end made the uptakes as expensive an item as the roof itself. Further to minimise erosion, recourse is had in many plants either to water-cooling or to the use of basic bricks in the uptakes. Some furnaces react very well to such modification ; in others there is a tendency for the slag pocket walls and arches to be unduly eroded by the gas-borne dust, which is not able to flux with the cooled, or basic, brick of the uptakes.

Roofs

The 12 in. roof without ribs is still very popular in this country, but the roof with alternate 12 in. and 15 in. ribs has many adherents. In the United States roofs are usually 18 in. thick, many of them with 22½ in. ribs. W. C. Buell[11] anticipates that still thicker roofs will be used in the larger sized furnaces. It is not uncommon for roofs to be thickened over the region of the taphole and charging doors, where the greatest amount of wear usually takes place.

Most operators now build the arch with a rise of about 1¼ in. to 1½ in. to the foot span : this is rather a steeper arch than was often found a few years ago. Many modern roofs are not level from end to end, but have a rise of from 1 ft. to 2 ft. from the ends to the middle.

Common practice until recently was to build roofs in single arches across the furnace, using four or five squares to each end-arch of standard commercial size. Where single arches are used, they are now often built with end-arches only, made specially to give the desired rise. Bonded roofs are favoured by a number of plants ; the objection raised some years ago that it was impossible to patch them appears to be unfounded. By means of a special shaped brick, a roof can be both bonded and ribbed, and if each brick is made an end-arch a very stable and durable structure is obtained. Some operators find that a bonded roof loosens in certain places during heating-up, and allows bricks to slip out ; in the author's experience bricks have slipped down, but never right out.

Before the present war a good deal of work was being done on the use of basic bricks in roofs. The installation

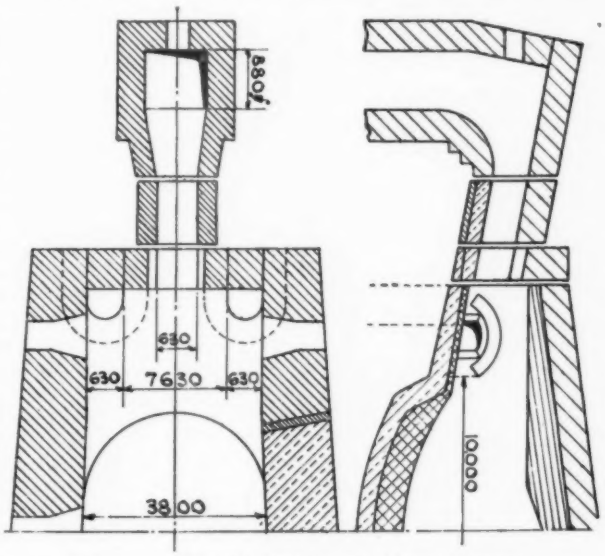


Fig. 7.—Design of block in the Moerz furnace.

of these roofs was accompanied by changes in engineering details. Most basic-brick roofs were carried between one fixed water-cooled skewback and one spring-loaded floating skewback. The shape of the roof could be controlled by a series of screws carried into a suitable structure. The engineering technique thus developed may well prove valuable in the construction and handling of silica roofs.

Roof life during the last few years has been less variable than formerly. The average roof life of 21 British basic furnaces considered by the Open Hearth Committee was 335.[5] Lives have been obtained with basic bricks in this country of 700 heats with 120-ton furnaces, and on the Continent basic roofs have lasted over 1,200 heats on 50-ton furnaces. The following figures were quoted by Rudorff[12] of the life of roofs in various countries :—

	Heat in Tons.	No. of Heats.
Great Britain	95–138 ..	485–300
United States of America ...	150–170 ..	500–350
Germany	30–116 ..	750–400

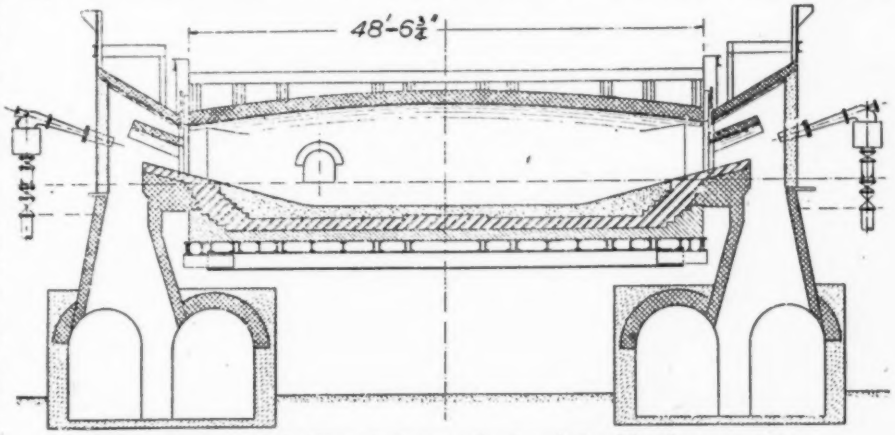


Fig. 8.—Section of the Hoesch furnace for burning cold coke oven gas.

F. C. Swartz. *Iron and Steel Engineer*, 1942, vol. 19, Jan., pp. 57–60.
A. E. Dodd and A. T. Green. Iron and Steel Institute Special Report No. 26, p. 9.

9 G. E. Rose and F. M. Washburn. *Iron and Steel Engineer*, 1930, vol. 7, July, pp. 394–401.
10 *Iron and Coal Trades Review*, 1921, Feb. 4, p. 162.
11 W. C. Buell, Jr. "The Open-hearth Furnace," vol 1, p. 193.
12 D. W. Rudorff. METALLURGIA, 1941, vol. 25, Dec.

The quality, and particularly the shape, of roof bricks has improved during the last few years; building technique has improved, and in many plants the heating-up of new roofs is under continual thermometric control. A report[13] by the Open Hearth Refractories Joint Panel is a good example of co-operation between furnace builder and furnace operator.

Suspended roofs have not made much headway. A promising line of experiment has been interrupted by the war; a report on a suspended basic brick roof was made in 1938,[14] but no further information is available.

The open-hearth furnace with a removable roof has a stout advocate in J. O. Griggs.[15] The general opinion among furnace operators is that at present there is not enough certainty of adequate financial return to justify the expenditure that would be incurred. The main benefit from the removable roof would be the ability to charge the furnace at a much increased rate, and some operators think that such charging would be too fast for the thermal capacity of the furnace.

Linings

Backwalls.—Increasing interest is being taken in fully sloped backwalls. Many newly built furnaces incorporate the feature. In the United States it is virtually standard on new furnaces, and no programme of modernisation of older American furnaces is carried out without the introduction of this feature. Typical examples of such modernisation were given by G. L. Danforth in 1940.[16] The sloped backwall is a usual feature of Russian furnaces, which are based very largely on American design.[12]

Frontwalls.—Basic brick has found a good deal of favour for frontwall pillars, either metalkase tubes or standard chrome-magnesite bricks being used. Archless doors have aroused interest, the elimination of the arch allowing a higher door opening to be used. Current practice with water-cooled door frames is to make them wider at the top than at the bottom, and to slope the frame so that the door lies closely against it. Water-cooled doors are used with satisfaction in a number of plants, and trials, as yet inconclusive, have been made with monolithic rammed doors.

General Structure

During recent years there has been a trend towards increasing the strength and rigidity of the structural steelwork of furnaces. Formerly a comparatively small number of binders of light section were used: these allowed ready access to the brickwork for repair purposes, but became distorted and so weakened the structure. In recent years hot repairs have become less frequently needed, and opportunity has been taken to use more, and stronger, steelwork. Slabs instead of joists are now commonly used for buckstaves, the slab section being as large as 16 in. × 6 in. Roof binders are usually rigid, adjustable tie-rods being but seldom used. A steel plate shell may be built inside the steelwork. Attempts have been made to render furnaces gastight by this means;[17] but usually the plating is not continuous round the furnace, being confined to such parts as the sloping backwall, where it is certain the brickwork will remain untouched throughout the campaign.

The technique of furnace building has been greatly improved over the last few years. Excellent results have been brought about by the co-operation of brickmakers with the designing, operating and building personnel within the works. An example of co-operative work in this field is given by P. W. Wood.[5]

Slag Pockets.—Enlargement of slag pockets has been undertaken wherever possible, in the attempt to make them large enough to run untouched throughout a furnace campaign. In the case of some enlarged furnaces, it has been impossible to make bigger slag pockets, and in these circumstances a furnace might have to be put off specially to remove some slag. Attempts to tap off the slag have been made, but the results are rather unpredictable; sufficient does not yet appear to be known of the nature of these deposits to make it possible to ensure that they will be fluid enough to run out when the wicket is opened.

Several works in this country have experimented with auxiliary slag pockets, but a reliable system does not appear to have been established. In the United States, on the other hand, considerable success with them is reported. British works, in the main, try to ensure that the pockets have ample size, and by a carefully arranged system of false floors and lazy walls, try to simplify the removal of the slag. Most works remove the slag by means of pneumatic picks, but the successful use is reported of Cardox and other explosives.

Regenerators

Structure.—Regenerator chambers are usually encased in steel plates. Opinion is divided as to the advisability of providing an air space between gas and air chambers or building a common wall. With the latter, some mixing usually occurs before the wall is rebuilt. With the former type mixing is avoided, and it is possible to use the space for melting-floor columns; but unless the space is wide or is adequately ventilated, it is liable to become hot, and so cause distortion of the steelwork.

Size.—Modern furnaces are being provided with relatively greater checker capacity than most older furnaces had. Sinclair Kerr *et alii* report[5] that a furnace with a checker capacity of 14·7 cub. ft. per sq. ft. of hearth surface made an output of steel of 42 lb. per sq. ft. of nominal hearth area, as against 34·5 lb. for a furnace with a checker capacity of only 7·34 cub. ft. per sq. ft. of hearth surface.

Method of Checkering.—There is little use of patent checker bricks in this country. Their price is high compared with standard shapes, and their salvage value is lower. Ordinary salvaged checker bricks provided they are not glazed and are of good shape and free from dust, may be used again without loss of efficiency. This is now being done with confidence as a result of an investigation by Chesters.[18]

Checkering is usually done with 9 in. × 4½ in. × 3 in. bricks giving 6 in. × 6 in. openings. There is an increasing tendency to use a 2½ in. brick, so that almost the whole of the material may take part in the heat exchange cycle. The report by A. Robinson[19] on the use of 3 in. / 2 in. side wedges has been followed in some plants. One American works has used this system with 2½ in. / 2 in. side wedges.

The use of open or staggered settings is usually determined by trial on individual furnaces. The setting must (*a*) be stable; (*b*) have openings small enough to ensure a high velocity of the waste gases, since the heat transfer depends on the velocity and the turbulence, and yet large enough to prevent early clogging by dust and fluxed checker brick.

Fireclay brick is generally used for the bottom two-thirds of the checker; some plants finish with semi-silica and a few courses of first-class silica on the top. High alumina firebricks are sometimes used on the top six to ten courses; these appear to be resistant to the slagging action of the dust and are durable in a hot-working checker. In a checker that works at a more normal temperature dust tends to deposit on them. Their salvage value is low, as they are very prone to break on removal.

To prevent premature stoppages, the height of bearer walls is being increased, while a suggestion has been made[7] to install steam blowers between the bearer walls and in the flues, so that the accumulations may be blown to the chimney.

(*Continued on page* 143.)

13 Open Hearth Refractories Joint Panel. *Journal of the Iron and Steel Institute*, 1941, No. II, p. 293 P. *et seq.*
14 "Steel Maker." *Sheet Metal Industries*, 1938, vol. 12, Dec., pp. 1373–1374.
15 J. O. Griggs. *Blast Furnace and Steel Plant*, 1941, vol. 29, Sept., pp. 1092–1094.
16 G. L. Danforth, Jr. *Iron and Steel Engineer*, 1940, vol. 17, Feb., pp. 66–67.
17 I. Semikin. *Stal*, 1939, No. 9, pp. 15–19.
18 J. H. Chesters. Proceedings of the Cleveland Institution of Engineers, 1939–40, p. 111.
19 A. Robinson. *Journal of the Iron and Steel Institute*, 1933, No. II, pp. 112–113.

A Metallurgical Study of German and Italian Aircraft Engine and Airframe Parts

Section I

THIS report constitutes a summary of data resulting from the metallurgical examination of German and Italian aircraft engine and airframe parts by the Aero Components Sub-Committee of the Technical Advisory Committee to the Special and Alloy Steel Committee formed for this purpose. Two sections are published in this issue, and the remaining sections will be presented in succeeding issues.

The parts examined represent an extensive range of the various types of enemy aircraft which have fallen into the hands of the R.A.F. since the beginning of the war.

The principal object of these investigations was to obtain data on the types and quality of materials used, methods of manufacture, efficiency of the heat-treatment to which the parts had been submitted, together with any other information which might prove of value, as, for example, details of the finish. Further, the influence of restrictions due to our blockade on enemy procedure and selection of materials was kept in mind. Attention was given chiefly to engine parts, but a number of airframe and miscellaneous components were included. Special features concerning design had been noted in certain instances, but these were not the primary object of the investigations.

For the purpose of this report, components of the same type from different aircraft have been considered together and the main features summarised. A section to be published later will contain a complete list of all the individual parts examined by the Committee, classified under the respective engines or type of aircraft, and for fuller details the individual reports should be consulted.

The Sub-Committee responsible for these investigations and for this report comprise Mr. W. H. Dyson, Ministry of Aircraft Production; Dr. H. Sutton, Royal Aircraft Establishment; Dr. R. Genders, Superintendent, Technical Applications Metals, Ministry of Supply; Mr. H. Bull, Messrs. Brown-Bayley's Steelworks, Ltd.; Mr. H. H. Burton, The English Steel Corpn., Ltd.; Mr. W. J. Dawson, Messrs. Hadfield, Ltd.; Dr. W. H. Hatfield, F.R.S., Chairman, Brown-Firth Research Laboratories; Mr. D. A. Oliver, Messrs. Wm. Jessop and Sons, Ltd.; Dr. T. Swinden, the United Steel Companies, Ltd.; and Mr. G. Stanfield, Secretary, Brown-Firth Research Laboratories.

The work included in this report embraces the results of investigations carried out from the beginning of the war until towards the end of 1941, but investigations have continued and are still in progress, and the work is being carried out meticulously. Naturally, no comparisons are made in the report with corresponding parts in British or American aircraft, neither are certain aspects, which the investigations have shown to be open to criticism, emphasised.

A Description of the Enemy Engines Examined

A BRIEF description of engines from which the parts examined were removed is of interest. The parts were taken from engines of four German series and one Italian. The German series comprised Jumo 211, Mercedes-Benz D.B. 601, B.M.W., and Bramo Fafnir. The first two engines are liquid cooled, and the second two air cooled. The Italian engine was the Fiat A80R.C. 41 radial engine.

Jumo 211 Series

The engine from which most of the parts were obtained was of the Jumo 211A type. The engine had been installed in a Heinkel 111 aircraft. Engines of the Jumo 211 series are also used in Junkers 87 and Junkers 88 aircraft. Other engines of the Jumo 211 series — i.e., Jumo 211B, 211D, 211F, and 211H — are in general only slight modifications of the 211A type.

The engine is a 12-cylinder super-charged inverted Vee, with liquid cooling, direct fuel injection into the cylinders, and spark ignition. The general design of the engine follows established practice.

The weight of the engine is low in proportion to the swept volume, 1,450 lb. and 35 litres respectively, but on account of the relatively low maximum engine speed the power output per litre is also low.

The crankshaft is of unusual design for a modern aero engine, the webs being in the form of flat plates extended to form balance weights. The plain and forked connecting rods are of normal design.

The cylinder liners are inserted in the cylinder block, and four long studs attached to ears near the crankcase end of the liner draw the liner against the cylinder head, into which it is spigoted. The pressure joint is made by a copper washer on a conical seating. Two rubber rings in grooves in the liner make the sealing joint between the liner and crankcase.

The valves for each cylinder bank are operated by a single camshaft driven by bevel and spur gears from the lower end of the auxiliary gearbox. The inlet and exhaust valves are of normal shape, the exhaust valves being sodium cooled, one exhaust valve per cylinder being fitted.

Lead bronze is used for the main crankshaft bearings and big end bearings, but the camshaft bearings and supercharger drive bearings are of aluminium-rich alloy.

The propeller is driven through a spur-type reduction gear, the driving and driven gears being splined to the shafts and centralised by split bronze cones. The driven shaft is mounted on a roller race at the rear end and on a combined roller and thrust ball race at the front housing cover.

The engine is well made, and there was no evidence of the employment of methods to economise labour.

Mercedes-Benz D.B. 601 Series (German)

Mercedes-Benz D.B. 601 engines are fitted in Messerschmitt 109, Messerschmitt 110, Heinkel 113, Heinkel 111P, and Macchi C. 200 aircraft. Most of the parts examined were from an engine of the D.B. 601A type.

The engine is of the 12-cylinder inverted 60° Vee super-charged, petrol injection, liquid-cooled type. The bore and stroke are 150 mm. and 160 mm. respectively. The swept volume is 33.9 litres, and the compression ratio 6.9/1.

The net dry weight is 1,400 lb. The engine is mounted by means of steel pins screwed into aluminium alloy flanges, spigoted into two positions on each side of the crankcase and held by studs. Various types of forged magnesium alloy cantilever mounting-cradle arms are employed.

The crankcase is an aluminium alloy casting internally ribbed to provide rigidity with lightness. Seven main crankshaft bearing bridges are machined to take bearing caps, and the main bearings are lead-bronze lined steel shells. The crankshaft is hollow and in one piece, with balance weights riveted to most of the crankweb extensions. The connecting rod assembly consists of plain rods of I section and forked rods of H section that run on three track roller crankpin bearings. Each track has 24 rollers, housed in a split duralumin cage and running on the crankpin. The outer race is a split steel shell.

Each cylinder block, including the heads and double-walled jackets, is a single aluminium alloy casting with dry liners. Steel cylinder liners, the ends of which bed on to the cylinder head to make a gas-tight joint, are screwed and shrunk into the block.

Two exhaust and two inlet valves are fitted per cylinder. All have hollow stems and the exhaust valves are sodium cooled. There is one hollow underhead camshaft for each cylinder block.

The airscrew reduction gears are of normal type and incorporate a short steel sleeve, so disposed as to allow some self-alignment in transmission. The airscrew shaft is hollow, to provide for a cannon firing through it.

The supercharger impeller is driven through a hydraulic coupling, and its speed is automatically varied with altitude.

The fuel pressure pump delivers to an injection pump, which consists of 12 separate pumps mounted in line and driven by an overhead camshaft. A control unit regulates the fuel delivery to give a predetermined mixture for change of boost, change in exhaust back pressure, and change in temperature of the air in the inlet manifold.

The workmanship and casting technique are good, and the engine is designed and conspicuously marked for quick detachment from and replacement in the aircraft.

The Mercedes-Benz D.B. 601N engine is very similar to the D.B. 601A, except that the compression ratio has been raised to 7·9/1 and the allowable speed increased from 2,400 to 2,800 r.p.m.

B.M.W. 132K and B.M.W. 801A (German)

The B.M.W. 132K engine is installed in Heinkel 115 float plane aircraft. The engine is an air-cooled, geared, 9-cylinder radial, direct petrol injection engine, with single-speed supercharger. The propeller is driven through epicylic reduction gearing. The cylinders have a 6¼ in. bore and 6¾ in. stroke (as the Pratt and Whitney Hornet engine), giving 27·7 litres swept volume. The compression ratio is 6·93/1.

The twin spur planet epicyclic reduction gearing for the propeller provides a ratio of 44/61 times crankshaft speed. Accessories and auxiliaries are driven through several trains of spur pinions radially disposed about a central driving shaft in the auxiliary gearbox at the rear of the engine. The net dry weight of the engine is 1,170 lb.

The engine is mounted on a tubular ring held by welded tubular Vee bracing to the front spar of the main plane.

The crankcase, in two portions bolted together, is cast in aluminium alloy. The crankshaft is in two sections, the shaft and crankpin being integral with the forward crank web. The rear web is bushed in the eye with an aluminium bronze liner, the bore of which is ground to a taper and highly burnished. The outer surface of the crankpin is ground with a high finish to a corresponding taper, on to which the crank web is pressed. The bore of the crankpin is inversely tapered on the same gradient to accommodate the insertion under a heavy load of a copper-plated steel-tapered plug which fits flush with the end of the crankpin. The tapered plug is internally threaded, presumably for extraction.

Eight auxiliary connecting rods of H section form a normal assembly articulated around the flanged big end of a master rod which carries a fixed steel bush lined with lead-bronze. The wrist pins are inserted from the front and located by locking plates. Gudgeon and wrist-pin bearings are phosphor bronze bushed.

The steel cylinder barrels and aluminium alloy heads are close finned, with a total radiating surface of about 20 sq. ft. The cylinder barrel is screwed and shrunk into the head.

The exhaust valves have hollow sodium-cooled heads and stems. The inlet valves are solid, with dished heads. The valve rockers are fitted with spun-in balls, flattened to make contact with the valve stems and held in screwed adjusters. They are mounted on fixed spindles in the bronze-bushed walls of the rocker-box. The rockers are actuated through ball-ended push rods and plain bearing roller tappets by cam-rings, one inlet and one exhaust. The cam-wheel is driven through a reduction gearing on the forward crankcase wall, giving a ratio of one-eighth crankshaft speed.

The front end of the crankshaft is internally bronze-bushed, to form a spigot bearing for the after end of the propeller driving shaft, which operates through the reduction gear.

The B.M.W. 801A engine is a 14-cylinder, 2-row air-cooled radial engine. It is installed in Dornier 217 and Focke-Wulfe Condor aircraft. Examination of this engine is not yet complete.

Bramo-Fafnir 323P.1 (German)

This engine is installed in Dornier 172 aircraft. The engine is a 9-cylinder radial, air-cooled, geared engine with petrol injection to the cylinders. It has a two-speed supercharger. The capacity is 26·8 litres, and the compression ratio is 6·23/1. The general design is conventional and includes American pattern cylinders, Farman type reduction gear, and bolt type Maneton jointed crankshaft. The engine weighs 1,320 lb. dry and 1,970 lb. when the airscrew, engine mounting, cowling and oil-cooler are included. The published take-off power is 989 h.p. (British units).

The crankcase proper is built up of two aluminium alloy pressings which are faced to join on the centre line of the cylinders. Steel housings for the main crankshaft bearings are pressed into the front and rear walls of the crankcase and pinned.

The steel cylinder barrels are screwed and shrunk into the aluminium alloy heads without any joint or locking device.

The exhaust and inlet valves are hollow, the former being sodium-cooled. The valves are operated by a cam-ring mounted concentrically with the crankshaft in a chamber in the front of the crankcase. The crankshaft is of conventional design, the two principal portions being joined together by a maneton joint of normal type. The connecting rod assembly also is of normal type. The big end of the master rod runs on a lead-bronze bearing cast on a steel bush, which is shrunk on the crankpin and located by a dowel. The articulated rods are of uniform H section with fixed bronze bushes at both ends.

The airscrew reduction gear consists of an epicyclic train of bevel wheels, and provides a ratio of 29 : 18.

The supercharger is driven from the rear of the crankshaft through a spring coupling and an epicyclic step-up gear that is arranged to give two alternative ratios, 9·6 : 1 and 12·4 : 1.

The engine mounting is a triangulated structure of the usual type, built up by welding.

Fiat A.80 R.C.41 (Italian)

The engine examined had been installed in a Fiat B.R. 20 twin-engined bomber. The engine is of the 18-cylinder double row supercharged air-cooled radial type, fitted with reduction gearing. The compression ratio 6·7/1. The cylinder bore is 140 mm. × 165 mm., and the swept volume 72 litres. Unlike the German engines examined, this engine employs a carburettor. The supercharger is of the single-speed type. The engine is of conventional design throughout, and has a very low power output per litre.

Section II—Crankshafts

THE eight crankshafts examined, taken from various types of German and Italian engines and aircraft, were of the following types :—

Six-throw Crankshafts

Report No. 1.—Junkers Jumo 211A (front portion only ; see Fig. 1).
Report No. 19.—Mercedes-Benz D.B. 601A (see Fig. 2).
Report No. 85.—Mercedes-Benz D.B. 601N. (see Fig. 3).
Report No. 124.—Junkers Jumo 211F 1 (see Figs. 4 and 5).
Report No. 132.—As Item 124 (portion only ; not illustrated).

Radial Crankshafts

Report Nos. 13 and 28.—B.M.W. 132K engine (see Figs. 6 and 7).
Report No. 44.—Bramo Fafnir 323P engine (see Figs. 8 and 9).
Report No. 82.—Fiat A80RC 41 (front half only ; see Fig. 10).

With the exception of the last mentioned, No. 82, the crankshafts were all of German origin.

In general, the surface finish and workmanship throughout were of a high order, and during the preliminary examination no fatigue flaws, cracks or defects were found. The centre journal of No. 19 showed severe overheating, probably owing to loss of lubrication, and the appearance of the pin of the Fiat crankshaft (No. 82) indicated heavy bearing pressures.

Chemical Analysis

The results of the chemical analysis of the crankshafts are summarised in Table I :—

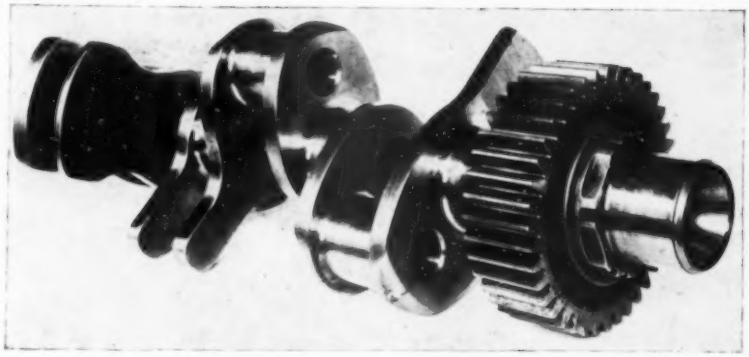


Fig. 1.—Front portion of Junkers Jumo 211A.

TABLE I.—CHEMICAL ANALYSES OF THE CRANKSHAFTS.

Report No.		C. %	Ni. %	Cr. %	Mo. %	V. %
	SIX-THROW TYPE.					
1	Junkers Jumo 211A	0·30	1·45	2·48	0·24	0·08
19	Mercedes-Benz D.B. 601A	0·18	1·78	1·85	0·34	Nil
85	Mercedes-Benz D.B. 601N	0·20	1·99	1·72	0·30	Nil
124	Jumo 211.F.1	0·31	2·03	2·44	0·22	0·12
132	Jumo 211.F.1	0·28	1·48	2·53	0·16	Nil
	RADIAL TYPE.					
28	B.M.W. 132K—Front half	0·16	1·92	2·14	0·25	Nil
13	Rear half	0·38	0·28	1·19	0·21	Nil
44	Bramo F. 323P—Front half	0·20	1·84	2·10	0·30	Nil
	Rear half	0·37	1·89	1·90	0·37	Nil
82	Fiat A.80RC.41—Front half	0·32	3·02	0·73	0·36	Nil

Both the nickel and the chromium contents fall approximately within the range of 1½ to 2½%, with two exceptions —namely, the rear half of the B.M.W. 132K crankshaft, which was a 1% chromium-molybdenum steel, and the Fiat A.80 R.C. 41 front half, which contained 3% of nickel and ¾% of chromium with molybdenum. An addition of vanadium was not usual, and was found only in two of the three Jumo crankshafts.

The samples can be further classified into carburised and non-carburised, and it will then be seen that the carbon content of the carburised steels varies from 0·16–0·20%, and for the non-carburised the carbon content ranges from 0·28–0·38%.

All the steels appeared to have been made by the basic electric arc process. The sulphur and phosphorus contents were low and ranged from 0·008 to 0·016% ; the standard of cleanness was high, similar to that being supplied to the British aeroplane industry.

Fig. 2.—Mercedes-Benz D.B. 601A.

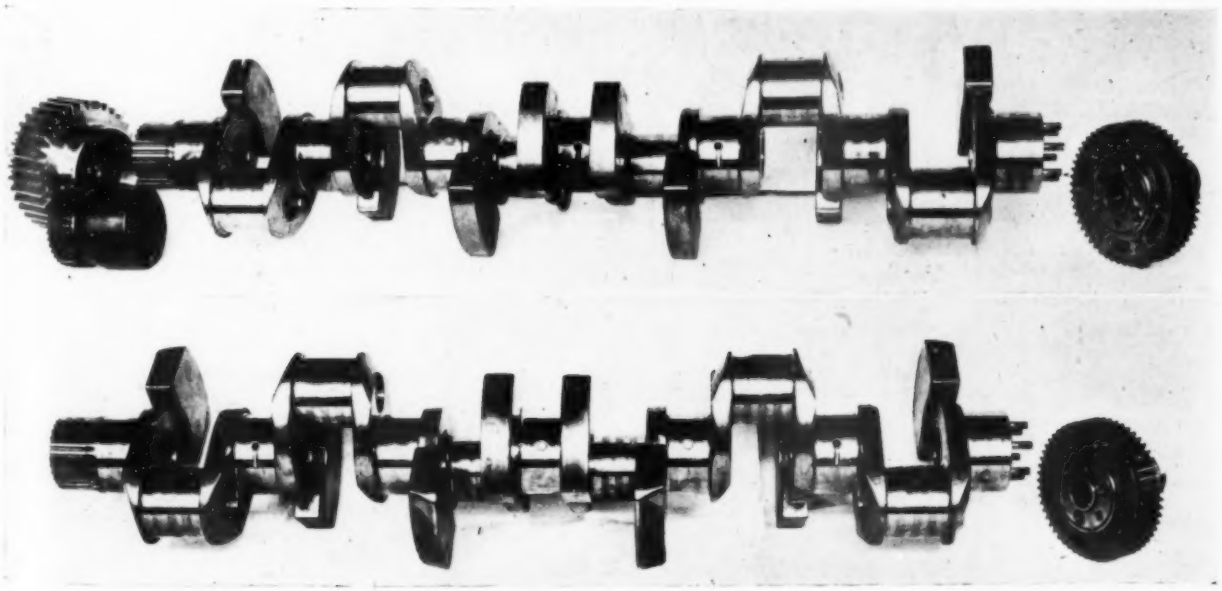
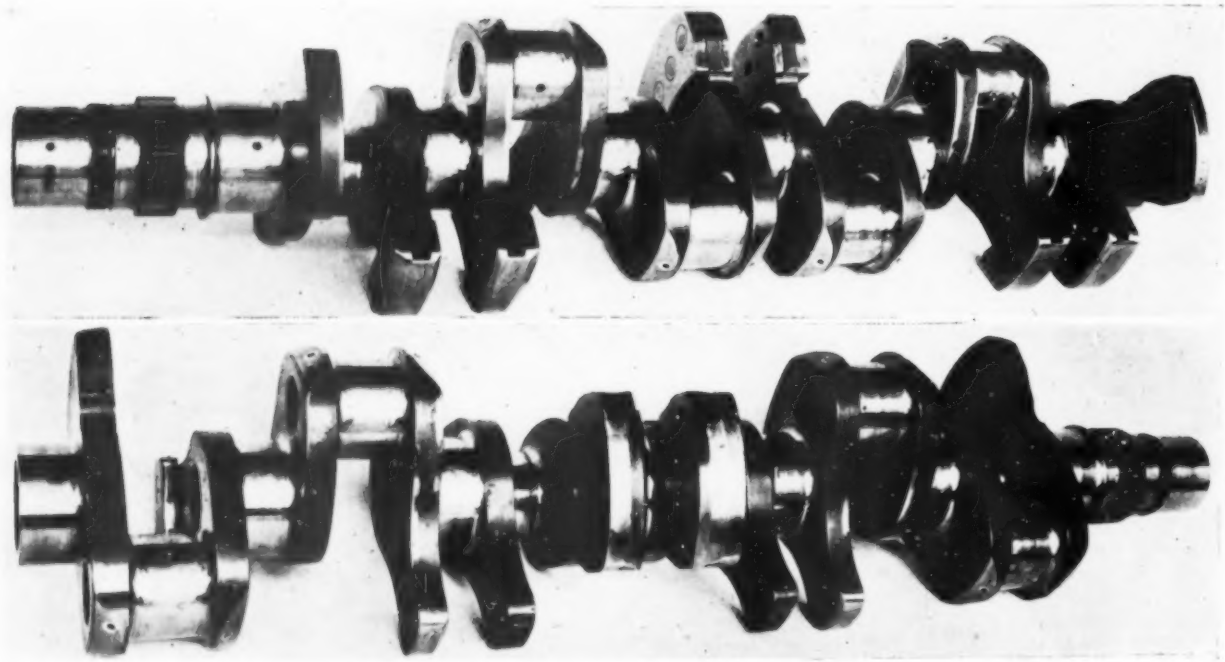


Fig. 3.—Mercedes-Benz D.B. 601N.



Figs. 4 and 5.—Junkers Jumo 211.F.1.

Method of Manufacture

Representative sections were prepared for sulphur printing and etching. No segregation was revealed, and the carburisation of pins and journals of those crankshafts which had been carburised was uniform, Fig. 11. Further etching with a cuprie reagent revealed a normal grain flow for stampings, but in general the allowance for machining appeared to have been greater than is usual in this country. Ink prints were prepared, and the dendritic structures generally indicated the use of a comparatively small size of ingot

Heat-treatment and Microstructure

The crankshafts may be classified again as follows :—

NON-CARBURISED.

Report No. 1—Junkers Jumo 211A.
" 13—B.M.W. 132K rear half.
" 44—Bramo F. 323P. rear half.
" 82—Fiat A 80 R.C. 41, front half.

CARBURISED.

Report No. 19—Mercedes-Benz D.B. 601A.
" 85 Mercedes-Benz D.B. 601N.
" 28 B.M.W. 132K. front half.
" 44 Bramo F. 323P front half.

NITRIDED.

Report No. 124—Jumo 211 F. 1.
" 132 Jumo 211 F. 1.

The crankshafts which had not been carburised appeared to have been hardened and tempered in a normal manner, the microstructures consisting of sorbite. The front end of the early Jumo crankshaft had been overheated slightly for hardening, but the other crankshafts of this group possessed fine-grained structures.

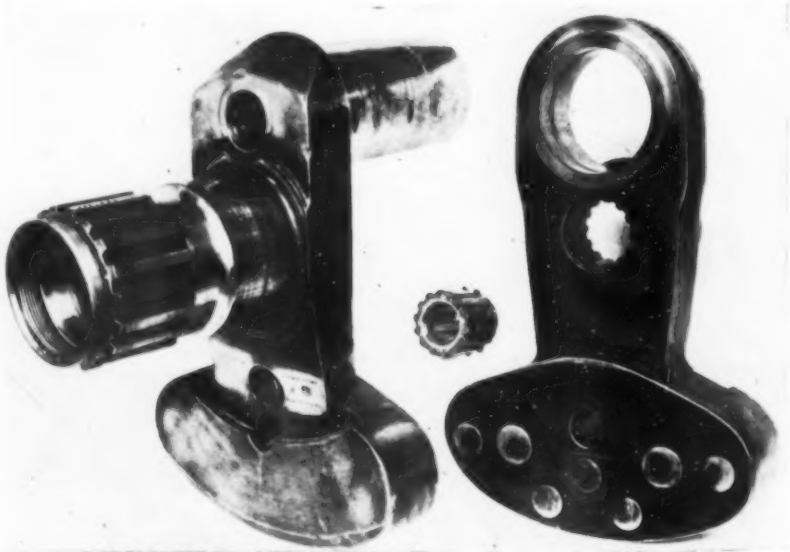
The total depth of carburisation was determined by micro-examination and by depth hardness and carbon determinations. Fig. 12 shows the results obtained on the Mercedes-Benz crankshaft.

The small amount of free carbide was in a finely divided form, and it is probable that there had been a diffusing heat-treatment after carburising. Both case and core structures of the above crankshafts were fine grained, and indicated a refining and hardening heat-treatment from the usual temperatures. The final heat-treatment probably consisted of a tempering at about 200° C.

The early Jumo crankshaft No. 1 had not been surface hardened, but the two

Report No.	Crankshafts.	Depth of Case.	Max. Hardness
19	Mercedes-Benz D.B. 601A	0·15 in.	730 V.P.N.
85	Mercedes-Benz D.B. 601N	0·20 in.	830 "
28	B.M.W. 132K—Front half	0·15 in.	800 "
44	Bramo F. 323P—Front half	0·05 in.	730 "

Figs. 6 and 7.—B.M.W. 132K engine.



Jumo 211 F. 1 crankshafts, although made from the same type of nickel-chromium-molybdenum steel, had been nitrided. This steel cannot be classed as a nitriding steel, and very considerable embrittlement had occurred.

A pronounced difference in depth of nitrided case was found, as shown by the hardness depth curves seen in Fig. 13. The case of greater depth possesses a lower maximum hardness, as shown by the curves. This was probably due to the use of an excessive nitriding temperature. A comparison of the nitrided cases (Figs. 14 and 15) will show that the crankshaft No. 124 possessed an abnormally large heat-treated grain size, and it was evident that the crankshaft had been overheated for hardening prior to nitriding.

Mechanical Properties

Tensile and impact tests were prepared from several positions in the crankshafts. The widest variation in maximum stress was found in the case carburised crankshaft from the Mercedes-Benz D.B. 601N engine, from which maximum stress values of 84 and 91·7 tons per sq. in. were obtained.

The following figures were selected from results of tests taken where the grain flow was longitudinal, but other tests were taken in a transverse direction, and these did not reveal any marked fall in ductility or toughness.

Fig 9.—Bramo Fafnir 323P engine.

The tensile results do not call for comment, but with reference to the Izod results it should be noted that the rear half of the B.M.W. 132K crankshaft (No. 13) was made from a 1¼% chromium-molybdenum steel.

TABLE II.—MECHANICAL PROPERTIES OF THE CRANKSHAFTS.

Report No.		Max. Stress, Tons/sq./in.	Elongation %	Izod Impact Ft.-lb.
	NOT CARBURISED.			
1	Junkers Jumo 211A	68·5	20·8	70, 75
13	B.M.W. 132K—Rear half	67·5	19·0	26, 21
44	Bramo F. 323P—Rear half	73·4	18·5	46
82	Fiat—Front half, A.80,R.C. 41	74·5	20·4	48, 51
	CARBURISED.			
19	Mercedes-Benz D.B. 601A	80·2	19·5	73
85	Mercedes-Benz D.B. 601N	84·9	17·5	51
28	B.M.W. 132K—Front half	81·6	19·6	55, 05
44	Bramo F. 323P—Front half	86·7	17·3	49, 46
	NITRIDED.			
124	Jumo 211.F.1	70·9	16·0	10, 11
132	Jumo 211.F.1	67·0	18·5	18, 19

Fig. 8—Bramo Fafnir 323P engine.

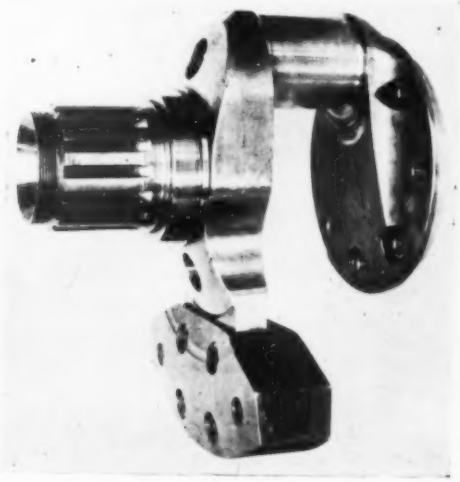
Reference has already been made to the embrittlement of the nitrided crankshafts Nos. 124 and 132.

Peculiarities of Design

Among the six-throw crankshafts, it will be noticed that the early Jumo crankshaft (No. 1), see Fig. 1, did not carry attached balance weights. All of the pins and journals were chambered, and the pins had been bored eccentrically.

The balance weights attached to the Mercedes-Benz D.B. 601A and D.B. 601N crankshafts consisted of three pieces riveted together, and rather heavier in the last-mentioned crankshaft (compare Figs. 2 and 3). The pins and journals had been bored and chambered concentrically. Mild steel tubes had been fitted inside the pins of these two crankshafts, and end caps of

Fig. 10.—Front portion of Fiat A. 80R.C.41.



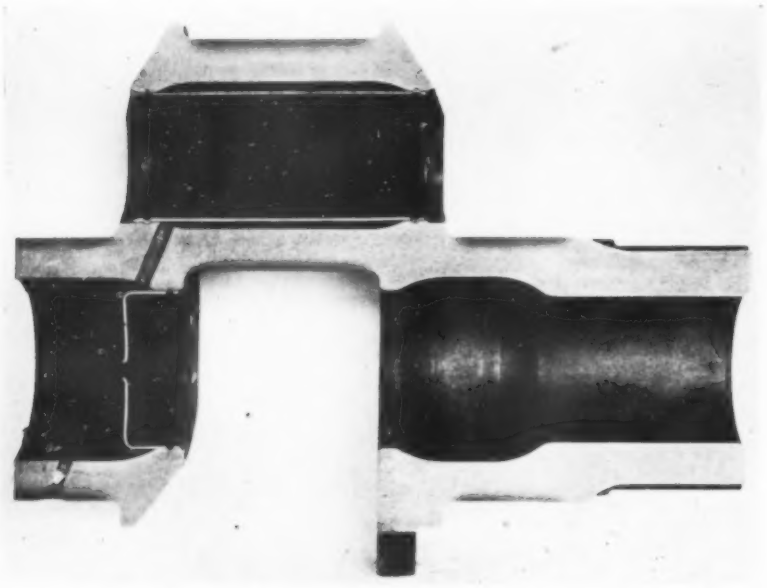


Fig. 11.—Section of Mercedes-Benz D.B. 601N, showing structure.

similar material had also been fitted to the journals of the Mercedes-Benz D.B. 601N crankshaft, as shown by the half section, Fig. 11.

It was also noticed that oil holes on the journals of the D.B. 601N crankshaft had been moved circumferentially 120° or 180°.

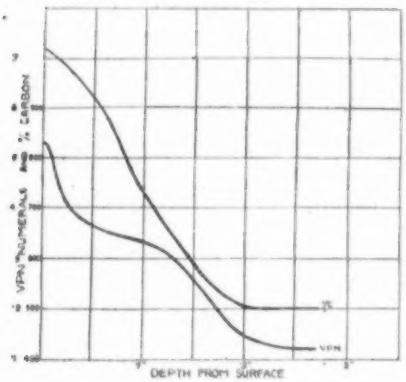


Fig. 12.—Depth of carburisation on Mercedes-Benz D.B. 601N.

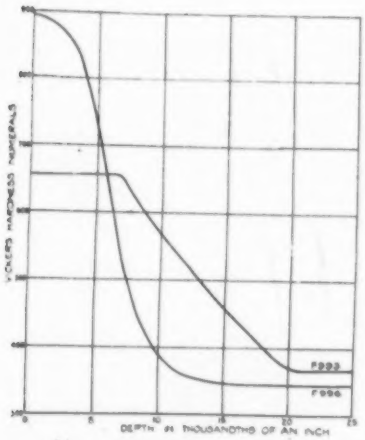


Fig. 13.—Depth of carburisation on Junkers Jumo 211.F.1.

Both these crankshafts of Items Nos. 19 and 85 carried a spring drive, which is shown with the crankshafts in photographs (Figs. 2 and 3), and one of them is shown dismantled in Fig. 16.

The two Jumo 211 F. 1 crankshafts were of similar design and were of unusually heavy construction. The radii of both pins and journals were most generous. The pins and journals had been chambered, and the pins had been bored eccentrically as with the early Jumo crankshaft. Each of the added balance weights was in one piece, riveted to the crankshaft.

Evidence of hammering and local grinding or dressing after hammering was found on several web faces of both crankshafts. One of these is shown in Fig. 17. It will be remembered that these two crankshafts had been nitrided, and it has been suggested that distortion had occurred during nitriding, and that the hammering was a part of a straightening operation.

All the crankshafts from the radial engines carried attached balance weights, which in the B.M.W. 132K and Fiat A 80 R.C. 41 had been riveted, (see Fig. 18, showing the rear half of the B.M.W. 132K crankshaft after dismantling), but the balance weights of the Bramo Fafnir 323P crankshaft had been bolted (see Figs. 19 and 20).

With the exception of the Fiat A. 80.R.C. 41 crankshaft in the construction of which a brass casting has been used, all the balance weights were carbon steel forgings riveted with mild steel, but the bolts on the Bramo Fafnir 323P crankshaft were in alloy steel. Those on the front half, see Fig. 19, were of 2½% chromium-molybdenum steel, and those in the rear 1¾% nickel 2% chromium with molybdenum. The latter bolts had been nitrided without embrittlement.

The two halves of the Bramo Fafnir 323P crankshaft were connected by a Maneton joint, as shown in Figs. 8 and 9. The Maneton bolt had been bored out and very finely finished, and was of the following composition :

	%
Carbon	0·46
Chromium	1·68
Molybdenum	0·36
Vanadium	0·21

heat-treated to 89 tons tensile strength, with an equivalent Izod figure of 23 ft.-lb. The nut was made from a 2½% chromium - molybdenum steel hardened and tempered to about 70 tons tensile strength, and a washer was of 2% beryllium-copper, having an equivalent tensile strength of about 65 tons per sq. in.

Among the auxiliary parts examined, the starter shaft, No. 29, fitted to the

Figs. 14 and 15.—Comparison of the nitrided cases of two Junkers Jumo 211.F.1 crankshafts. x 250.

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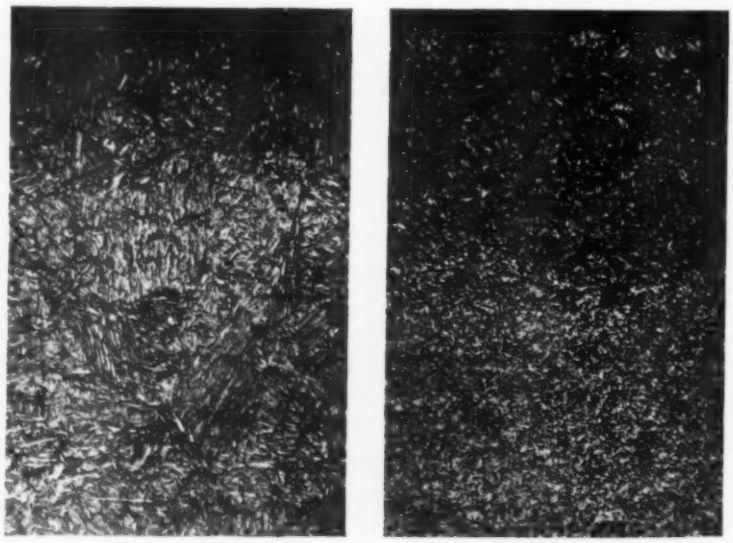


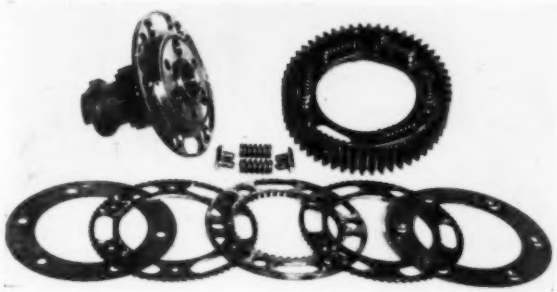
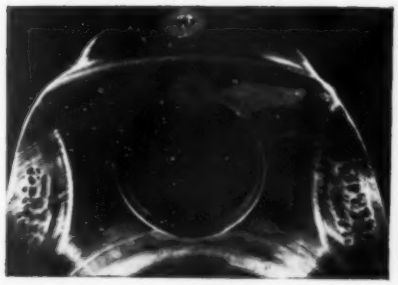


Fig. 16. (Left)—Dismantled spring drive for Mercedes-Benz crankshaft.

Fig. 17. (Right)—Evidence of hammering and local grinding found on web faces of two Jumo 211.F.1 crankshafts.



rear half of the B.M.W. 132K crankshaft was of special interest. The overall length of the shaft was 13½ in. and 1 in. diameter in the shaft portion. Fig. 21.

The chemical analysis was as follows:—

	%
Carbon	0·18
Manganese	1·07
Nickel	0·18
Chromium	1·26
Molybdenum	0·27

Both ends of the shaft had been formed by an upsetting operation, and both splined portions and the hand-starter dogs had been locally carburised. Subsequently, the shaft as a whole had been given a case-hardening heat-treatment involving a final quench in water from about 800° C. As a result the carburised portions were fully case-hardened, and the shaft showed a hardness gradation having an equivalent tensile strength of 100 tons per sq. in. at the surface to 72 tons tensile at the axis.

General Conclusions

The examination of several crankshafts taken from German and Italian aeroplane engines has not disclosed any novel features of design, but has shown that they were made from materials of first-rate quality. There has been no evidence to indicate any shortage of alloying metals.

The early Junkers Jumo six-throw crankshaft and three others quoted on page 132 were not case-hardened, but the remaining crankshafts had been case-hardened after carburising the pins and journals, and only the most recently examined Jumo 211 F.1 crankshafts had been nitrided. It is surprising that the enemy should have been so slow to realise the advantages of nitriding.

The crankshafts appear to have been made by drop-forging in a manner similar to that employed for aero crankshafts in this country. Most of the six-throw crankshafts had been fitted with separate balance weights, and it is thought that the object of this was to simplify the drop-forging process, which is always more difficult with large integral balance weights than with the much lighter type provided on most of these German components. We assume that in some cases one die operation might be saved by adopting the German design, but on the other hand machining processes would be increased, and it is probable that the final crankshaft is less satisfactory than one in which the balance weights are integral with the rest of the shaft. Figs. 19 and 20 illustrate the complicated machining processes for bolts and balance weights which would be necessary in the production of the German type of six-throw crankshafts, whilst Fig. 18 illustrates the processes required in the case of a radial crankshaft (B.M.W. 132K fitted with separate balance weights).

Fig. 19.—Front half of balance weights of Bramo Fafnir 323P crankshaft dismantled, showing bolt fixings.

Fig. 20.—Rear half of balance weights of Bramo Fafnir 323P crankshaft.

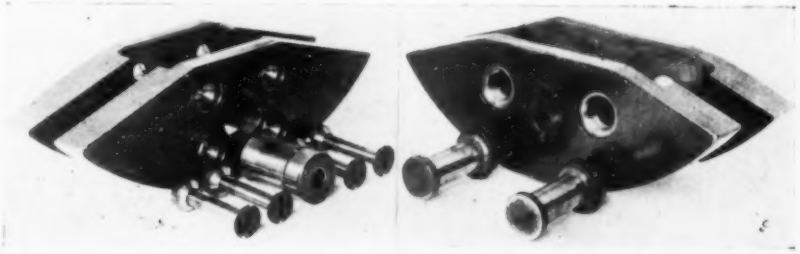


Fig. 18. — Rear half of B.M.W. 132K crankshaft dismantled, showing riveted balance weight.

An interesting design feature which differs from any British practice of which we have knowledge is the joint between front and rear halves in the B.M.W. 132K crankshaft.

The reason for the peculiar design of the Italian Fiat A. 80.R.C.41 crankshaft is not known with any certainty, but it seems probable that the intention has been to avoid the Maneton type of joint, of which there would usually be two in a double row engine. Assuming that the large diameter coupling in the centre is used as a bearing, however, the possibility of very high peripheral speeds seems likely to be a disadvantage. It should also be noted that the Italian design necessitates the employment of a split master rod as compared with the solid-ended rod, which can be used with the Maneton joint coupling.

The heat-treatment in most instances had been effectively performed, but two cases of overheating for final hardening were found, and an excessive nitriding temperature also appeared to have been used for one of the Jumo 211.F.1 crankshafts.

Mechanical testing revealed high values for ductility and toughness commensurate with the tensile strength of the materials except for the two nitrided crankshafts. In these the impact values had dropped from an original estimated figure of 70 ft.-lb. to as low as 10 ft.-lb. It should be noted that, in our experience, the steel could not be classed as a satisfactory nitriding steel.

Some interesting features were found in the Bramo Fafnir 323P crankshaft, which was constructed with a normal type Maneton joint. The Maneton bolt was of unusually high-tensile strength (89 tons/sq. in.), and a beryllium-copper

Fig. 21.—Starter shaft fitted to the rear half of the B.M.W 132K crankshaft.

washer was used in conjunction with the nut, the latter being heat-treated to 70 tons tensile strength.

The conservation of oil by rolling in tubes of mild steel into the chambered pins of the Mercedes-Benz crankshafts, forming an annular space, was of interest.

The two Jumo 211.F.1 six-throw crankshafts most recently examined were the heaviest aeroplane crankshafts we have yet seen, and all the radii were exceptionally generous.

In most cases the workmanship was of a high order, and in this respect the only exception which could be made was the very severe hammering for straightening which had apparently been given after nitriding to the two Jumo 211.F.1 crankshafts.

The series of German crankshafts seems to include three stages of development, commencing with a non-hardened type and passing through a carburised and case-hardened type to the two nitrided shafts, which were the last examined. It is most surprising in view of the liking shown by the Germans for the 2.5% chromium-molybdenum steel in other directions, that a similar steel has not been employed for aero crankshafts.

(Connecting rods and gudgeon pins will be considered in the next issue.)

The Importance of Alloy-Scrap Segregation

FROM time to time reference is made in this journal to the ever-expanding metal requirements imposed by war conditions and to the need for conserving supplies in order that there will be no waste or needless destruction. The importance of making the most efficient use of combinations of metals in the form of alloys is generally appreciated, and contributes to the conservation of metals, when they are carefully compounded and used with proper discretion, but there is ample room for economy in the use of alloys by segregating efficiently the alloy scrap for re-use.

This conservation of metals is as much a problem in the United States as in this country, and the particular aspect of the subject which is concerned with alloy-scrap segregation is admirably presented by Hertz* who points out that the tremendous use of alloy steel in the present war effort is one of the outstanding developments in the iron and steel industry. Alloy steels are used in armour plate, guns, tanks, aeroplanes, battleships, and the mechanised equipment so vital to modern warfare. The success of all of our offensive and defensive weapons is predicated on the use of alloy steels superior in performance to those of our enemies. For this reason, if for no other, the maximum utilisation of available alloys is absolutely necessary.

The increase in the use of alloy steels has brought about a severe strain in the supplies of the alloying elements. For many of these elements we depend upon importations in ships for the major percentage of the total available material. This is true of manganese, chromium, vanadium, tungsten, nickel, molybdenum and many other elements, and every effort must be made to reclaim to the greatest possible extent the alloys which find their way into iron and steel scrap as a result of varying manufacturing operations.

In the manufacture of alloy steel, a great many alloying elements are used either singly or in combination. These combinations involve not only the use of two or more alloys, but also the use of these alloys in variable concentrations in the steel. After the steel is made and poured into ingots, it is rolled or forged into a diversity of products which are then dispatched to the trade. Once the products have entered the trade, they are subjected to various operations, such as forging and machining. In the conversion from ingot to dispatched product, there are certain irrecoverable losses, and a certain amount of scrap results which can be recovered and returned to the melt shop. In the consumer's plants, there is additional scrap produced in the various finishing operations, and in many cases the scrap contains a large proportion of the alloy originally used in the melt. The proper recovery and utilisation of this scrap, both in the producer's and consumer's plants, is of great importance in our war effort, as the scrap amounts to a source of strategic alloys which can be used in addition to the virgin alloys brought into the steel plants.

The importance of scrap recovery is illustrated in the case of 3·5% nickel steel by comparing the net tons of ingots produced per 1,000 lb. of new nickel from four practices, figures for which are given in Table I:—

TABLE I.

	Ingots per 1,000 lb. of new Nickel. Tons net.
1. All new nickel used	12·8
2. Steel plant revert scrap recovered	16·9
3. Steel plant revert scrap and finished-operation scrap recovered	22·8
4. Steel plant revert scrap and refinishing-operation scrap recovered for special case of low finishing yield	31·2

From these figures, the very great importance of recovering alloys from scrap can be readily seen. With a complete job of recovery in revert and finishing operation scrap for an average product, the tons of nickel-bearing ingots have been almost doubled over that which would have been produced if all new nickel had been used.

The same relative tonnages of ingots hold for alloy steel containing molybdenum, tungsten, and cobalt because these elements are not oxidised during the steelmaking process, and are thus almost 100% recoverable. Chromium and vanadium are oxidised in the steelmaking process to a large extent, and their recoveries are low compared to the elements previously mentioned unless certain special practices are followed in certain special grades of electric-furnace steel.

With modern steelmaking methods, including rapid methods of analysis, the use of alloy scrap presents two problems:—

1. The ability to obtain the scrap in proper form for charging.
2. The certainty that the scrap charged will contain no alloys which are not permissible in the particular heat involved, or that these alloys are at least in amounts under the maxima specified or desired.

Consider first the type of scrap required for charging. Heats are slowed up and excessive losses by oxidation are encountered if the scrap consists of light bushy turnings which have a low bulk density and which in many cases are impossible to charge into a furnace in a reasonable length of time. Such turnings should be prepared in any manner that will increase their bulk density to the point where it becomes possible to charge them satisfactorily. This may be done by crushing, or briquetting, or both. Many other types of scrap can be charged direct or can be prepared by crushing. However, the question of utilising the alloy-scrap can be safely left to the producing plants; the main point is to see that alloy-scrap is efficiently segregated and returned to the steel producers.

* C. H. Hertz, Jr., *Mechanical Engineering*, vol. 64, No. 6, 432.

Electro-Tinplate

W. E. Hoare, B.Sc. (Eng.)

Tin Research Institute.

The current tin shortage has caused attention to be sharply focused on electro-tinning, with its recognised adaptability to the production of extremely thin coatings. Present indications are that it may be one of the keenest weapons at our disposal for tin conservation. Electro-tinning is a recognised industrial process, but its application in the production of tinplate is a comparatively recent development, and this authoritative review of the process indicates its possibilities for conserving tin without undue reduction of the quality of the tinplate.

A NUMBER of technical and economic features have caused considerable attention to be directed, over the past ten years, towards the production of tinplate coatings by electro-deposition. The major proportion of tinplate steel basis is now made by the continuous cold-reduction process, and produced up to the stage of the tinning operation, in the form of coiled wide strip. Up to the present, continuous hot-dip tinning of strip has not been found practicable except on relatively narrow widths, and the interest of large tinplate undertakings has naturally turned towards the electro-deposition process which has been demonstrated as adaptable to the coating of wide strip in continuous lengths.

A second relative technical advantage of the electrolytic process is that it permits the application of tin coatings of any desired thickness. The grade of hot-dipped tinplate widely employed for container-manufacture carries about 0·00008 in. thickness of tin on each face, and it is not easy, with the hot-dipping process, to keep the coating thickness consistently below this order. Electro-deposited coatings can be plated as thin or as thick as is reasonably desired, and thus the amount of coating can be exactly matched to the required service of the material.

The current tin shortage, arising out of the Far Eastern situation, has caused attention to be sharply focused on electro-tinning, with its recognised adaptability to the production of extremely thin coatings. Present indications are that the process may be one of the keenest weapons at our disposal for tin conservation, and strong efforts to promote the early adoption of electro-tinning on a wide scale are being made both in this country and in the United States.

The matter of coating uniformity is important. Hot-dip tinners have been seeking for many years, with some success, to improve the uniformity of their coatings, but examination of commercially produced tinplates shows that strong variations are sometimes encountered. The electro-deposition process is not free from the disadvantage of producing non-uniform coatings, but on general grounds it would appear that the latter process holds better prospects for controlling the variables that affect coating thickness.

The general picture would not be complete were reference not made to certain real advantages of the hot-dip process. The first is that the hot-dip method is a widely known and understood process, with a progressive history of success in producing an efficient and cheap food-packaging medium. Equally successful application of electro-tinplate in this field has yet to be proved. The question of appearance is unworthy of much attention at present, but the mirror finish of the hot-dip coating as compared with the matte surface of the straight deposited electro-coating must be allocated as a point in favour of the former process. Developments are noted below which take care of this point, however. Adhesion of the coating and strength of soldered joints must be taken as generally better with hot-dipped than with electro-coatings, and this last consideration has stimulated intensive current researches aimed at bringing *thin* electro-deposits up to the line of thicker hot-dipped coatings.

The general project is of important magnitude. Just before the war, world production of tinplate was of the order of four million tons annually, the United States producing about one-half and this country about one-fifth of the total. Tin consumed by the industry totalled around 70,000 tons out of an overall world consumption of 180,000 tons. Arising out of the present situation, the Governments of this country and the United States are aiming at a 50% cut in tin consumption, and it therefore devolves upon tinplate manufacturers to save at least 35,000 tons of tin a year. This economy must be effected without undue reduction of the quality of the fabricated products,

Courtesy of U.S. Bureau of Mines.

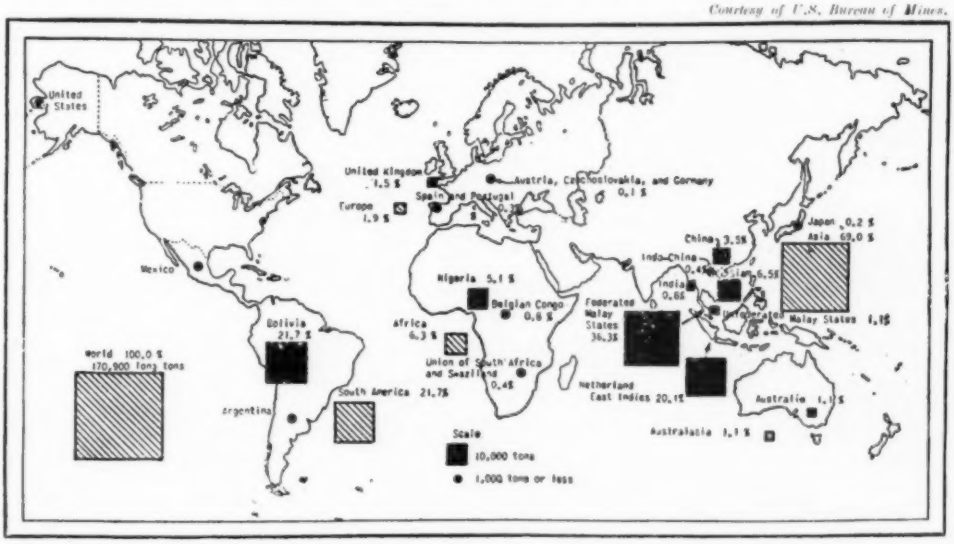


Fig. 1—Geographical distribution of world tin production in 1930. The effect of the Japanese intrusion in the Far East on the availability of tin is clearly seen. Transport is also a problem—very little tin is produced close to where it is consumed.

munitions, and food containers into which the material is formed, and achieved in spite of shortages of other raw materials, such as rubber, lacquers and solders. It is considered that thinly coated electro-tinplate is the only visible expedient which will give a strong enough answer to the urgent necessity for tin conservation.

Although it is difficult to take a long-term view, it would seem to be arguable that the future of the tinplate industry in the post-war period will be closely associated with the electrolytic process. If current expectations are fulfilled, electro-tinplate will use tin in a very efficient way, thus stimulating a post-war extension of the applications of tin-coated steel into new fields.

Recent American estimates* give an interesting perspective of the type and volume of tinmill products. These estimates refer to the United States industry in 1943.

Approximate tin available to the industry	24,000	tons
Approximate requirement of tinmill products	76,000,000	boxes
Less quantity for which no tin is allocated	6,000,000	,,
	70,000,000	,,

Thus a quantity of 24,000 tons of tin is available to satisfy the requirement of 70 million boxes of protected tinmill products. A recommended approach is given as—

Process.	Requirement in Boxes.	Tons of Tin Used.
Hot-dipping (average coating 1·25 lb. basis)	30,000,000	17,300
Electro-tinning (average coating 0·5 lb. basis)	30,000,000	6,700
Chemically treated blackplate	10,000,000	—
	70,000,000	24,000

It is conceded that the extension of electrolytic capacity will mean a permanent deduction from hot-dip production. In view of the fact, however, that in certain cases the saving of tin is only acceptable under war-time conditions, some post-war reversion may be expected.

Thickness of Coating

In the tinplate industry the coating is usually quoted as a weight per unit area, rather than as a thickness. The unit of area is the basis box, 31,360 sq. in. of plate (e.g., 112 sheets, 20 × 14 in.). The weight is expressed in pounds and ounces (U.K.) or pounds and decimals of a pound (U.S.). One pound per basis box is equivalent to 0·00006 in. thickness of coating on each face of the plate. This nomenclature has been inherited by electro-tinplate and will be used in this review.

The 1 lb. to 1½ lb. coatings normally used by the packaging industries impart good corrosion resistance and soldering quality to the plate. The coating protects the steel from deterioration during shipment and storage of the tinplates and the finished containers, prevents spoiling of the foods or other materials packed, provides a surface capable of being soldered at high speeds on automatic lines, and provides a good base for thin, continuous lacquer films. Not in all cases have every one of these requirements to be filled at one time, however. In some cases only protection from rusting during shipment is required, and here the indications are that a very light coating of the order of 2 oz. per basis box may suffice. Good soldering quality may be provided by a coating of 8 oz. per basis box. Summarising the problem as it is seen at present, the lightest coatings may be employed where only superficial protection is needed; the intermediate coatings of about 8 oz. weight will be used for normal soldered-seam packages and will cover the widest field; finally, a small volume of more heavily coated plate will be in demand for special purposes.

Electro-Tinning Processes

Electro-tinning is a recognised industrial process that has been in use for many years for the plating of fabricated articles of steel, brass and copper. The plating of mild steel in sheet or strip form, or, in other words, the production of electro-tinplate, is, however, a comparatively recent development.

* T. W. Lippert, *Iron Age*, April 30, 1942.

The stannous chloride (alkaline stannite) electro-tinning bath was the first to come into fairly wide usage, and due to the fact that this process gave rather variable results, electro-tinning was viewed at one time with some measure, of suspicion by industrialists and engineers. This situation is now completely changed, however. Improved plating baths have been evolved as the result of well-directed research work, and electro-tinning is accepted as an established process of high reliability and wide application.

The Alkaline Process (*Stannate Bath*).—This process is in extensive use for still-plating fabricated articles of steel, brass, copper, etc., to specified coating thicknesses from 0·0001 in. up to several thousandths. The earlier alkaline baths used insoluble anodes, and while satisfactory results could generally be obtained, the replenishment of tin via the solution constituted a drawback, particularly in large-scale and automatic plants. The more recent and favoured alkaline plating solutions work with soluble anodes and combine excellent throwing power with the production of smooth compact deposits.

The working principles of the modern alkaline bath were discovered by Wernlund and Oplinger in 1931. They found that anodic replenishment of the tin content of the bath is satisfactorily achieved if the anode current density is kept high enough and the free alkaline content low enough, so that a thin greenish yellow oxide film is maintained on the anodes during the plating operation. Subsequent wide programmes of research and technical development, carried out notably by research organisations in America and by the Tin Research Institute in this country, have supplemented this basic discovery; outlining principles and methods of control so that the process works over a wide range of conditions that are easily controlled and maintained in practice.

The electrolyte consists essentially of a solution of sodium stannate and caustic soda; a typical make-up is as follows:—

Sodium stannate ($Na_2SnO_3\ 3H_2O$)	100 g. per litre.
Free caustic soda (NaOH)	12½ g. ,,
Hydrogen peroxide (H_2O_2)	½ g. ,,

The voltage drop across the busbars is about 4 volts, and a 6- or 8-volt generator is therefore suitable and gives an adequate margin for safety and control. The bath is worked hot, and optimum working conditions for regular depositing on steel may be summarised approximately as—

Temperature	75° C.
Current density	15 amperes per sq. ft.
Tin content	40–45 g. per litre
Free caustic soda	12·5 g. ,,
Efficiency	85%

Under these conditions a tin coating of normal tinplate thickness is deposited in about 6 mins., while the thinner coatings now under consideration are plated in very short times—e.g.,—

2 oz. per basis box (0·0000075 in.)	40 secs.
8 oz. ,, ,, (0·00003 in.)	2½ mins.

The Acid Process.—Although the acid bath is used to some extent for still-plating, its main use has been along the lines of barrel tin-plating and plating steel strip (America) and sheets (Germany) to produce electro-tinplate. The modern acid tin-plating bath depends for its successful operation on the use of addition agents, and recent history of development has been much concerned with investigation of the effects of such agents on the working properties of the stannous sulphate electrolyte. An excellent discussion of the development of the acid bath and a review of the somewhat complicated patent situation has been given recently by Pine.

The acid tin-plating electrolyte consists essentially of a solution of stannous sulphate and cresol-sulphonic acid with addition agents, a typical composition being—

Free sulphuric acid	85 g. per litre
Tin content	30 g. ,,
Cresol sulphonic acid	100 g. ,,
Gelatine (or lysalbic acid)	2 (1) g. ,,
β Naphthol	1 g. ,,

The maintenance of the bath in correct condition over long working periods is not difficult, and any loss of covering power or smoothness is corrected by making up losses of addition agents caused by drag-out or decomposition. The bath is worked cold, and the voltage drop is just under 1 volt. Suitable operating conditions for rapid plating are—

Temperature	Room temperature 18° C.–43° C. not critical).
Current density	From 10 amperes per sq. ft. for still-plating up to 300 or 400 amperes per sq. ft. when agitation is possible or the work is passing rapidly through the bath.
Tin content.....	20–35 g. per litre.
Efficiency.....	95–100%

Under these conditions and with a current density of 10 amperes per sq. ft., coatings of normal tinplate thickness are deposited in about 4 mins. With the higher current density possible in continuous strip-plating, thin electro-tinplate coatings are deposited in a matter of a few seconds.

Choice of Plating Bath for Electro-tinplate

The choice of the most suitable plating process for electro-tinplate raises some interesting issues. It is useful just to consider what properties are required in the finished material, and these may be summarised as the highest possible corrosion-resistance for the lowest possible coating weight, soldering properties close to those of hot-dipped tinplate, so that automatic can-fabricating lines can use the material without extensive modification, ability to take a thin continuous lacquer film, and reasonably good appearance.

rated too high. With the alkaline bath there is not the possibility for increasing current density that exists with the acid bath. This means that plating times cannot be shortened, and to get high output rates the size of vat must be increased or units duplicated.

Although necessitating extra equipment, the fact that the alkaline bath requires heating is not altogether a disadvantage. With thin coatings the question of drag-out of plating solutions becomes an important economic factor. For example, in some cases almost as much tin is dragged out in the adhering plating solution as is plated on to the work. Thus steps for recovery of drag-out must be taken and with the heated alkaline bath tin-containing rinses may be used to make up evaporation losses, providing a fairly simple routine for process economy.

The major advantage of the alkaline electrolyte is that it has an intrinsic cleaning action on work placed in it, and therefore the process demands a somewhat less critical cleanliness of the steel surface prior to plating. The effect of this feature is probably seen in the fact that knowledge derived from long experience of relative thick coatings on fabricated steel indicates that the alkaline bath (in straight comparison with the acid bath) gives coatings of better corrosion resistance and solderability. Similar differences appear to exist with the thinner coatings of about 8 oz. basis. These findings may adduce an argument either in favour of developing the alkaline bath for thin electro-tinplate, or for improving the acid bath coatings to bring

Fig. 2.—Weathering tests on electro-tinplate. Showing the very great increase of corrosion resistance obtained by the thin flash of tin. *Courtesy of the Tin Research Institute.*

Uncoated tin-mill blackplate. *0·0000075 in. tin coating.* *0·00003 in. tin coating.*

A considerable amount of experience is accumulating as the result of intensive study of these requirements, and it can be stated that there does not appear to be any major obstacles in the way of securing electro-tinplate with these desired properties from either the acid or alkaline baths; realising at the same time the great saving of tin which the present situation demands.

Aside from the quality of the deposit obtained, the arguments for and against the two types of bath in the field of electro-tinplate are complicated by plant considerations, such as installation costs, power demands, and heating requirements; by questions relative to the types of basis material available, whether strip or sheet, hot-rolled or cold-rolled; and by administrative aspects comprising patent rights, availability of labour with the required skill and consideration of capital expenditure needed to install a unit of plant.

The cathode current efficiency of the acid bath is 90–100% (Sn^{II}) and that of the alkaline bath 75–80% (Sn^{IV}). The acid electrolyte deposits about 2½ times more tin per ampere hour than the alkaline bath, and its resistance is about one-half. It may be taken that low-voltage D.C. power cost for working the alkaline process is about ten times that for operating the acid process. This ratio is in favour of the stannous sulphate electrolyte, but power costs are a comparatively small proportion of total coating costs (cf. a recent American figure of 60 cents per ton in high-rate areas), and this advantage of the acid process should not be

them up to the quality of the alkaline coatings. Actually, both lines of approach are being pursued. Current work indicates that the thin acid bath coatings can be brought up almost to level standard with those from the alkaline bath.

It is interesting to note that in one American installation a process is used whereby the steel is given an initial "flash" coating in an alkaline electrolyte and subsequent build-up is carried out in the acid bath.

The type of electrolyte used does not greatly affect the cost of installation except with very small units, where the alkaline bath might be expected to be very slightly more expensive. The major factor affecting the cost of a single installation is, of course, the form in which the basis steel is available. A unit plant for handling wide strip would be much more costly than a unit for processing single sheets.

Summarising the arguments affecting choice of plating solution, it cannot be said that either process shows sufficient advantage to secure its universal adoption in favour of the other. The situation is reflected in the position that plants based on both processes are running and in building for strip tinning in America; while in this country plants for handling sheets are intentionally designed to suit either type of electrolyte.

(To be concluded.)

(A list of references will be given at the end of the review.)

An Investigation of the Factors Governing the Adhesion of Tin-base Bearing Metals

By W. T. Pell-Walpole, B.Sc., Ph.D., J. C. Prytherch, B.Sc., and B. Chalmers, D.Sc., Ph.D.

This investigation comprises three sections and forms part of a programme of bearing metal research being carried out in the laboratories of the Tin Research Institute. In the first section the bonds obtainable in forming lined bearings are considered, and various factors which may affect the efficiency of the adhesion are examined. The second section deals with the strength of the bond, and gives a standard set of conditions likely to give the maximum bond strength. In the concluding section the current methods of testing adhesion of white metal bearings are discussed, and a new method of measuring the tensile strength of the bond is described. The work is fully described in the Journal of the Institute of Metals, from which this article is abstracted.*

METALLURGICAL CONSIDERATIONS

The object of bonding tin-base bearing metals to a bronze or steel shell is to obtain a composite bearing of which the bearing surface shall have the good anti-friction properties and embeddability of the tin alloy, while the bearing as a whole shall have the strength and rigidity of steel or bronze. In the ideal case there would be perfect metallic continuity, with the gradual transition of mechanical and thermal properties on passing from the lining to the backing material. This can be realised in a pair of metals which form continuous solid solutions. Pairs of metals which have mutual solubility enable the ideal conditions to be approached, but metals which form brittle intermediate compounds give the least satisfactory type of bond.

For a given pair of metals, the most effective bond will only be obtained if the surfaces are chemically clean, in contact throughout their extent, and maintained at a suitable temperature for such a time that mutual diffusion can occur. In practice, this generally requires one of the metals to be liquid. Cooling the composite bearing to normal temperatures must be so conducted that no contraction cavities, stress cracks, or other discontinuities are formed in or near the transition zone.

The Nature of the Bond between White Metal/Steel and White Metal/Bronze

In bonding tin or tin-base alloy to steel or to bronze, an ideal bond cannot be obtained, since the equilibrium systems tin-iron and tin-copper each contain a number of intermetallic compounds of restricted solubility range. These compounds are hard and brittle, and cause marked discontinuity of properties at the region of the bond.

The effect of a brittle layer between two ductile materials should be least harmful when the layer is as thin as possible and has each of its surfaces deeply interlocked with the more ductile material on either side. The thickness of the layer can be varied by control of the time and temperature of the reaction. The dendritic form at the compound interface will only be of advantage if the interstices between the crystals of the compound phase are completely filled with the tin-base alloy, since interstitial cavities would be likely to cause severe stress concentration and thus be a serious source of weakness.

The Factors Affecting Efficient Bonding in Practice

The lining of tin-base bearing is normally carried out in two distinct stages :—

1. The formation of the bond between tin or a tin-base alloy and the steel or bronze backing material, generally referred to as the tinning process.
2. The casting of the bearing alloy on to the pre-tinned shell.

* *July, 1942.*

The process of tinning has been discussed in a number of publications which have dealt with many factors affecting the wetting and subsequent ease of alloying of a solid by a liquid metal, including the effect of time and temperature of immersion, the method of mechanical or chemical preparation of the solid surface, the action of various fluxes, and the effects of minor constituents and inclusions in the solid article. Some experimental evidence of the effect of some of these variables on the resultant bond strength is given in the second section.

Casting the bearing metal is a combined alloying and casting operation. The tin-base alloy must be united to the tin of the " tinned " steel or bronze shell, and the composite bearing must then be cooled to normal temperature without impairing the efficiency of the bond. The tinned surface must either be cleared of any oxide skin which would prevent the molten bearing metal from uniting with it, or the shell must be maintained above the melting point of the tin and the molten bearing metal fed to it in such a manner that the oxide skin will float to the surface of the final lining. The latter method is frequently adopted in die-casting practice.

If the shell has been " tinned " with pure tin or with an alloy mechanically weaker than the lining alloy, then the latter must be kept liquid for sufficient time to permit complete mixing with tin on the surface and in the interstices of the compound layer ; otherwise the final bond will be weak. Some experimental evidence of the part played by the interstitial material on the adhesion strength was obtained during bonding tests (recorded in the second part of this paper) on certain alloys which can be improved by heat-treatment. When these alloys were lined on to steel or bronze shells, the subsequent heat-treatment produced an increase in bond strength proportional to the normal increase obtained in the alloys.

The pouring temperature is of great importance, and must not be high enough to permit excessive oxidation of the stream of metal, or oxide skins may get trapped in or near the bond. In practice, the copper content of the white metal determines its liquidus, and this fixes the minimum pouring temperature that can be used without risk of separation of some of the Cu_6Sn_5 crystals. Cadmium, when present, increases the tendency to oxidation, though not seriously below 450°–500° C., and this temperature is rarely reached in practice.

Cooling the Composite Bearing

When the process of bonding is complete, it remains to cool the composite bearing to ordinary temperatures without impairing the bond. The chief factors controlling the cooling process are alloy composition and rate and direction of cooling, and these may conveniently be considered in various stages, thus : (1) Cooling to the liquidus. (2) The

separation of small amounts of primary and secondary compound phases—e.g., Cu_6Sn_5 and SbSn. (3) The solidification of the tin-rich matrix. (4) Cooling of the solid bearing from the solidus of the alloy to normal temperatures. Considerable attention has been given to the rate and direction of cooling in the casting, resulting from investigations made under industrial conditions.

The effect of variations in alloy composition, mould design, temperature of metal and mould, were examined with regard to hand-pouring, die-casting, and centrifugal methods of production. A hypothesis is advanced to show that shrinkage cavities at or near the bond, the formation of which is controlled by factors investigated, may constitute a frequent and severe cause of poor adhesion. The conditions of operation necessary to counteract this trouble are suggested.

THE MEASUREMENT OF THE ADHESION OF TIN-BASE BEARING METALS TO VARIOUS BACKING MATERIALS

Previous investigators have confined their work to the strength of bond existing at room temperatures. In the present work bond strength has been studied from room temperature to 150° C., and information has been obtained from a study of shear and tensile tests on composite specimens of white metal and steel or other backing material.

As a result of much preliminary work, the following set of conditions was adopted as a standard preparation procedure. The mild steel was degreased cathodically in hot caustic soda solution, pickled for 1 min. in boiling 10% hydrochloric acid, fluxed with zinc chloride, and tinned at 400° C. for 15 secs., the excess of tin not being removed by shaking. The tinned specimen, when cold, was placed in a split mould heated at 170° C. in an air oven. White metal (7% antimony, 3·5% copper, remainder tin) was cast on at 350° C., and the mould was rapidly cooled in water. The white metal was liquid in contact with the steel for about 20 secs.

Bond results were obtained from composite specimens of types A, B, C, and D (Fig. 1) made from mild steel and white metal. These results, tabulated in detail in Table I, show that consistent values of bond strength can be obtained both in shear and tensile tests; in later tables of results, the individual values are not given as a rule, and the average value recorded is the mean value of six separate tests of type A, Fig. 1, at the particular temperature studied. All results are expressed in tons/sq. in.

TABLE I.

Type (see Fig. 1).	Temp., °C.	Bond Strength, Tons/in.².	Average, Tons/in.²
Tensile test-pieces—type A.	20	9·3, 9·3, 9·4, 9·8, 9·8, 9·3, B	9·5
	50	7·6, 7·6, 7·6, 7·9, 7·9, 8·2, BM	7·7
	100	5·4, 5·5, 5·4, 5·5, 5·6, 5·5, BM	5·5
	150	3·8, 4·2, 3·6, 3·8, 3·6, 3·8, BM	3·8
Tensile test-pieces—type B.	20	5·8, 5·7, 5·8, 5·8, 5·8, 5·7 M	5·8
	50	5·1, 4·7, 4·6, 4·8, 5·1, 4·7 M	4·8
	100	3·5, 3·5, 3·5, 3·7, 3·6, 3·6 M	3·6
	150	2·2, 2·2, 2·4, 2·2, 2·2, 2·4 M	2·3
Shear test-pieces—type C, external fillet	20	4·2, 4·1, 4·2, 4·1, 3·6, 4·1	4·0
	50	3·2, 3·2, 3·4, 3·4, 3·4, 3·5	3·3
	100	2·4, 2·4, 2·4, 2·4, 2·3, 2·4	2·4
	150	1·5, 1·5, 1·4, 1·6, 1·5, 1·6	1·5
Shear test-pieces—type D, internal fillet	20	4·1, 4·3, 4·3, 4·0	4·2
	50	3·0, 3·4, 3·6, 3·3, 3·1, 3·2, 3·9	3·4
	100	2·7, 2·2, 2·5, 2·5, 2·1, 2·4	2·5
	150	1·8, 1·7, 1·3, 1·6, 1·6	1·6

Since the metal always fails in preference to the bond in type-B specimens, it is evident that the results give no indication of bond strength other than that it is greater than the tensile strength of the white metal. By increasing the thickness of white metal, as in type A specimens, the metal fails under a higher stress, thus enabling the bond to be tested at a higher stress than in type B. It is still possible for the metal to fail in preference to the bond, in which case a cone of metal is torn out of the body of the white metal. This type of fracture is denoted in the tables by M and the figure given is less than the strength of the bond. Failure at the bond is denoted by B, and gives a true measure of bond strength. BM indicates that some metal adheres to the steel after fracture; in this case the bond strength is somewhat greater than the value recorded. The type A test was adopted as standard.

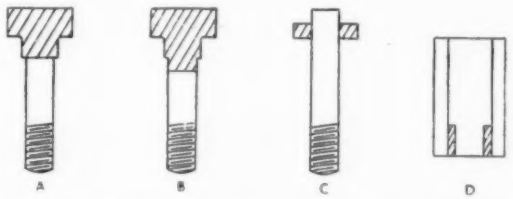


Fig. 1.—Composite specimens for bonding tests.

A and B.—Tensile specimens, with cross-section of white metal (A) greater than, and (B) equal to, that of steel. C and D.—Shear specimens with (C) external and (D) internal fillet of white metal. White metal shown cross-hatched.

The high temperatures of tinning employed in the preceding tests was adopted after the following series of tests had justified its use. For the lower temperatures of tinning it was necessary to use the eutectic mixture of zinc chloride and ammonium chloride for fluxing, but, as shown later, this should not affect the validity of the results. The temperatures at which studies were made were 240°, 250°, 300°, 350°, 400° C., and, as an extreme case, 500° C. Dipping time was 15 secs., and the excess of tin was not removed by shaking. Tinning at 350° C. or above gave the highest and most consistent results, but at 300° C. and below the fractures showed no adhering white metal, and the results were no longer so consistent. Increase of tinning time from 5 to 60 secs. had little influence on bond strength, except when tinning is carried on at a temperature as low as 300° C., in which case the best bonds are not obtained unless the time of dipping is about 30 mins. Results are given in Table II.

TABLE II.

Variables Studied.	Composition, % (balance Tin).		Tensile Bond Results, Tons/in.²			
			Temperature of Testing, °C.			
	Sb.	Cu.	20.	50.	100.	150.
(a) Surface Finish.						
Fine polish	7·0	3·5	8·9 B	7·4 BM	5·2 BM	3·4 BM
Fine machine polish			9·2 B	7·3 BM	5·2 BM	3·6 BM
Coarse machine finish			8·8 B	7·4 BM	5·3 BM	3·5 BM
Filed surface			8·7 B	7·4 BM	5·4 BM	3·6 BM
(b) Tin Coating.						
Excess tin coating	7·0	3·5	8·9 BM	7·2 BM	5·4 M	4·2 M
Thin tin coating			8·8 BM	7·3 M	5·2 M	4·0 M
(c) Influence of Flux.						
Fused zinc chloride 300° C.	7·0	3·5	8·8 BM	7·4 M	5·6 M	4·0 M
Fused zinc-ammonium chloride 300° C.			8·9 BM	7·4 M	5·4 M	3·9 M
Cold aqueous zinc chloride			8·5 BM	7·3 BM	5·4 M	3·7 M
Cold aqueous stannic bromide			8·8 BM	7·3 BM	5·4 M	3·7 M
(d) Tinning Conditions. / *Rate of Cooling.*						
350°/15 secs. / Slow cool 1½ mins.	7·0	3·5	7·5 BM	6·3 B	4·7 BM	3·6 BM
400°/15 „ / „ 1½ „			7·0 B	6·8 B	5·1 BM	3·5 BM
350°/15 „ / Quick cool 15 secs.			8·8 B	7·5 BM	5·2 BM	3·7 BM
400°/15 „ / „ 15 „			8·9 BM	7·7 BM	5·2 BM	4·0 BM
(e) Mould Temperature. / *Casting Temperature.*						
180° C. / 350° C.	7·0	3·5	7·0 B	4·7 B	2·7 B	1·4 B
200° C. / 400° C. (Brush Fluxing)			6·4 B	5·5 B	3·2 B	1·7 B
250° C. / 400° C. (Brush Fluxing)			7·0 B	6·1 B	4·8 B	3·0 B
(f) Coating.						
Thin, yellow film not removed	7·0	3·5	—	—	5·4 BM	—
Thin, yellow film removed			—	—	5·5 BM	—
Thick, yellow film not removed			—	—	5·5 BM	—
Thick, yellow film removed			—	—	5·3 BM	—

With the small mould employed in these tests it was found that when the white metal was cast at 350° C. into a mould at 170° C. the metal was completely solid in 2 mins. when allowed to cool in air. When chilled in cold water, this time was 15 secs. The influence of cooling rate of 15 secs. was compared with that of 2 mins. The results in Table

II (*d*) show that slow cooling (2 mins.) reduces the bond strength.

Tests were made in which the mould temperature was varied from 80° to 250° C., the white metal being cast at 350° C. in all cases. With the mould at 80° C., bonding was not completed over the whole of the steel surface; with mould temperatures at 150° C. and upwards consistently good bonds were obtained.

Bonding of standard white metal to many different backing materials was studied and numerous tests carried out. These included bonding to copper, wrought iron, medium carbon steel, "silver" steel, nickel steel, 10% tin bronze, phosphor bronze, brass, leaded bronze, and cast iron. The influence of changes in composition of the white metal has been studied, including those metals likely to be present as impurities. Certain of the new alloys examined are susceptible to heat-treatment, and the influence of this treatment on bond strength has been investigated.

ADHESION TESTING IN BEARINGS

The current practice is to judge the adhesion by means of the chisel test and by means of the effect of bending the lined shell. These methods should only be regarded as rough control methods. It became necessary, for this work, to establish a test in which the actual strength of the bond is measured. A local test is desirable because it is known that the adhesion may vary from one part of the shell to another. It is not known whether bond failure to service occurs by tension or by shear, but it is evident that a weak bond will be detected by either type of test. The following method of testing, in which the tensile strength of the bond is determined, fulfils these conditions; it is, however, subject to the limitation that it cannot be applied in its present form to bearings with a lining less than about 0·15 in. thick. It is, therefore, generally only suitable for measurements on shells as cast and not after finishing.

A small plug A (Fig. 2) of the white metal is isolated from the surrounding white metal by cutting with a pipe drill; the internal diameter of this drill is 0·35 in. A hole B, ¼ in. diameter, is then drilled through the steel shell, being finished with a flat-ended or D drill, so that it just penetrates into the white metal. The two holes are co-axial.

The test consists in pushing the plug A away from the shell by means of a force applied by a plunger through the hole B. The test is carried out in a tensile testing machine by means of a device illustrated in Fig. 3. The force

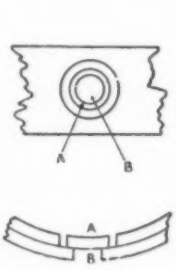


Fig. 2.—Method of drilling specimens for tensile bond strength.

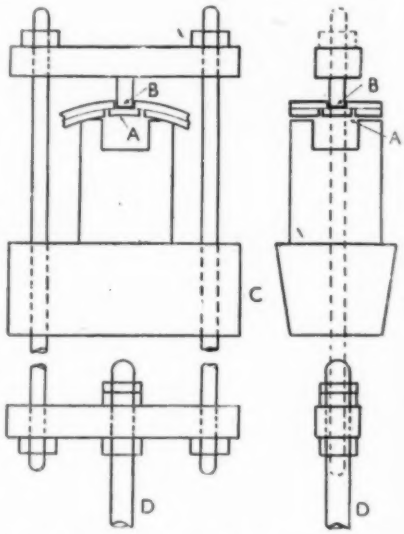


Fig. 3.—Apparatus for tensile bond test.

A, plug of white metal. B, hole in steel shell. C, grip for upper jaw. D, rod held in lower jaw.

required to detach the plug A is measured, and the bond strength in tons/sq. in. is calculated by dividing this force by the area of the annulus between the hole B and the trepanning cut in the white metal. If the white metal is too thin, it fails by shear instead of by tension at the bond, and the plug is not rigid enough to fracture the whole bond simultaneously.

Numerous tests have been made by this method, and it has been found that the maximum figure reached is equal to the tensile strength of the white metal. The results sometimes vary considerably from one part of a shell to another, and it is therefore desirable to carry out a number of tests on each shell that is examined.

Performance Tests on Brake Drum Cast Irons

Factors that determine the life of any brake drum are complex; apart from the metal used, design of the drum, selection of the lining and adequate ventilation are contributing factors in brake-drum life. Defects take the form of scores and heat cracks, which are briefly discussed and results are given of some performance tests.

A BRAKE drum is part of a mechanism that converts energy of motion into heat. The amount of heat generated and the speed of dissipation of this heat are, therefore, the main factors that determine the life of any brake drum, and they are factors which, theoretically, appear simple of analysis and calculation, yet practically are bewildering in their complexities. In the severe service of the modern drum, heat is often generated much faster than it can be dissipated, and also this can occur more times than the drum can withstand without developing serious and objectionable defects. Such defects, which take the form of scores and thermal cracks, have been discussed recently by O. Smalley,* and the results of performance tests on four types of brake-drum cast irons have been summarised.

The cause of scoring in brake drums appears obvious. A particle of sand or foreign material finds its way into the brake mechanism, and locating on the surface of the brake lining starts a cutting action under the pressure of braking. Each of the small particles of metal removed becomes embedded in the brake lining and act individually as cutting tools by removing more and more from the surface of the brake drum—a process which is cumulative until the drum is badly worn and the lining cut up and loaded with metal. Drum distortion causing extremely high pressures over localized areas is also a common cause of scoring. A too abrasive type of brake lining, or a lining that is harder than the drum, or a lining that wears in powdery form, or other conditions of the lining that cause cutting of the drum surface will result in scoring. To reduce scoring, first consideration should be given to the proper selection of lining to drum material or drum material to

* *Metals and Alloys*, 1942, vol. 15, No. 2, pp. 256–262; No. 3, pp. 405–411; No. 4, pp. 595–598.

lining, but in either case the nature of the service and the design of the drum are also factors which cannot be ignored. Dragging brakes, failure to release brake pressure immediately after the stop is completed, and unnecessary abrupt stops are important contributing factors.

Another common cause of scoring is overheating, but a drum scored because of overheating does not necessarily display thermal cracks, for the surface may wear away almost as fast as the cracks are formed, and often only a close examination will reveal minute thermal cracks. The remedy for scoring through overheating lies in the selection of an iron with larger quantities and a better distribution of graphite in a harder matrix, or in the use of a softer lining or a better design of brake mechanism. Scoring in waves or grooves is often an indication of free areas of ferrite, and the presence of this constituent always tends to reduce wear, cause pick-up and galling, and to end in uneven wear. The use of cast irons containing over 0·4% phosphorus are thought to favour scoring on account of the tendency for particles of hard friable phosphide to fall loose from the base metal and become embedded in the lining. Cementite in a relatively close form is considered undesirable, as hard spots result on machining and scoring difficulties follow. The presence of cementite also causes rapid and uneven wear of the lining, since the softer pearlite matrix wears away, leaving a hard cementite in relief to act as a cutting tool. Freedom from slag particles in form of manganese sulphide is quite a factor in the life of a brake drum, particularly in resisting scoring.

Thermal cracking is the term applied to a visible network pattern of cracks appearing over the surface of a drum. When a brake is suddenly applied, the surface of a drum tends to expand, but is constrained by the adjacent cooler metal, so that expansion can take place in one direction only, thus setting up stresses of such magnitude that incipient cracks are started, surface particles spall off, and the structure of the surface of the drum may be entirely changed to a completely soft or very hard material, according to the kind of cast iron used and the severity of the braking conditions, etc. The expansion and contraction which takes place would not have an important influence in itself were the heat rapidly and uniformly dissipated, and if the expansion and contraction were of simple form. Both cast iron and steel, however, when heated pass through a series of volume changes which may be so opposing that when the immediate outer layer may be expanding, the underlying material may be contracting, or the outer layer may be contracting when the underlying material is expanding. On cooling, the outer layer may be contracting while the underlying material is expanding, and but a few seconds later the outer layer will be expanding and the underlying material contracting. In addition to suffering these violent and opposing volume changes on heating and cooling, in cast iron carbides may dissociate into ferrite and graphite, and there may be a further structural change in the form of a swelling or lengthening of the graphite flakes. With such conflicting and opposing contending forces and changes of structure, the quantity and form of the graphite in the original drum castings and also the form and stability of the structure of the matrix have a profound influence on the life of any brake drum.

To correlate and evaluate the quality of a brake-drum iron with actual service life is a difficult matter, and any endeavour in this direction must be done under closely controlled conditions that bear some relation to the mechanical features of braking which are to be used and to the conditions likely to be encountered in service, but avoiding such extraneous influences as are imposed in actual road service and which cannot be connected directly with the brake-drum metal problem. To investigate such conditions, a series of brake-drum cast irons were subjected to dynamometer and scoring tests.

The four types of cast-iron tests included a standard "GD" Meehanite cast iron, a molybdenum cast iron, a high-tensile cast iron, and a nickel-chromium cast iron. The composition of the last three irons are given in Table I, together with their tensile strength and Brinell hardnesses. The best results were obtained with the "GD" Meehanite cast iron, which had a structure containing no free ferrite, only traces of phosphide and pearlite of an exceedingly fine nature bordering into sorbite. The molybdenum iron, which showed quite marked thermal cracking, had a structure consisting of well-distributed graphite, patches of molybdenum ferrite around the graphite flakes and fine pearlite. Such a structure should, in the absence of alloys, possess an exceptional resistance to thermal cracking, but would have a poor scoring value. A discolouration appeared on the surface of this drum and penetrated deep into the cracks. The high-tensile cast iron proved decidedly inferior to the first two irons so far as resistance to thermal cracking was concerned, and was only very fair in its scoring value. Discolouration was not so great as in the molybdenum iron, possibly due to the cracks not penetrating so deep as a result of the graphite flakes being neither so large or so numerous. The nickel-chromium cast iron had a high resistance to scoring, but a poor resistance to thermal cracking. Cracks penetrated deeper than in any of the other irons tested.

TABLE I.
COMPOSITION OF THREE CAST IRONS TESTED.

Composition.	Molybdenum Cast Iron.	High Duty Cast Iron.	Nickel-Chromium Cast Iron.
Carbon	3·48	3·03	3·26
Silicon	1·89	2·09	1·92
Manganese	0·94	0·80	0·86
Sulphur	0·104	0·068	0·098
Phosphorus	0·17	0·104	0·108
Nickel	—	—	1·23
Chromium	—	—	0·25
Molybdenum	0·75	—	—
Tensile strength, tons/sq. in.	—	18·0	19·0
Brinell Hardness	207–219	217	227

The tests show that any study of brake-drum materials must be made under conditions approaching actual service operations as nearly as possible. Scoring was shown to take place when the temperature gradient developed in the drum was not steep enough to set up the mechanism of revisal of expansion and contraction of the metal itself, and thermal cracking occurred when the temperature gradient between the braking surface and the centre of the drum was too steep for the drum to take care of. Apart from the selection of a metal of such structure as will enable it to accommodate itself to alternating stresses at elevated temperatures, design of the drum, selection of the lining and adequate ventilation are all contributing factors in brake-drum life.

The Basic Open-Hearth Process To-Day

(*Continued from page* 128.)

The use of auxiliary checkers that increased the regenerative capacity of a furnace by 30% is reported by L. F. Reinartz.[20] He eliminated all valves in the flues by installing Isley stacks and control, and used the space for the auxiliary checkers.

Flues and Valves.—The modern tendency is very marked: whenever space and time permits flues are being made larger and valves straighter. The straight-through slide valve is being increasingly used in place of the butterfly valve, with its tortuous passage and air leaks. The mushroom type of valve for producer gas is not so quickly being superseded. W. Trinks[21] says the slide valve is a failure unless water-cooled. T. Grey-Davies[22] reports that the water-cooled slide valve when used as a gas valve gets a tar deposit which interferes with its operation, but that dry slides made of heat-resisting steel lessen the deposition and give satisfactory results.

20 L. F. Reinartz. *Iron and Steel Engineer*, 1940, vol. 17, Feb., p. 76.
21 W. Trinks. *Iron and Steel*, 1941, vol. 14, March, p. 208.
22 T. Grey-Davies. *Sheet Metal Industries*, 1938, vol. 12, May, p. 522.

The Vagaries of 4S11

By Bernard Thomas, F.Inst.P., F.Inst.F.

Some results obtained from an investigation of the heat-treatment of a small forging in nickel-chromium steel to specification 4S11 are described; they show that accepted temperatures of treatment do not meet all conditions.

MOST steels for aircraft purposes conform within reason to the treatment temperatures as laid down in the ruling specifications. Examples of noteworthy exceptions have been mentioned previously in these pages,[1, 2] but the object of these further remarks is to deal specifically with 4S11.

Nickel-chromium steel to specification 4S11, or its non-permitted contemporary En. 23, is probably the most used and popular for the 55–65-ton tensile range for the production of drop-forgings and stampings. While its composition is generally known, the typical average analysis is shown in Table I for the purpose of refreshing the memory.

TABLE I.
Typical average analysis of steel to Specifications 4S11.

	%
Carbon	0·31
Silicon	0·19
Manganese	0·54
Sulphur	0·026
Phosphorus	0·025
Nickel	3·19
Chromium	0·71
Molybdenum	0·22

Speaking from experience, a ruling forging thickness of 3 in. is approximately the limit where 4S11 material is employed. With such sections a satisfactory response is usually obtained from the normal quenching temperature of 830° C., with oil as the quenchant, and tempering may be executed by temperatures in the neighbourhood of 600°–650° C., according to cast analysis and effect of mass. Instances are few where the lower limits of the temperature range are sufficient to reduce hardness to that specified.

With smaller forgings, however, particularly those of flat types, where a ruling thickness of only $\frac{3}{4}$ in.–$\frac{5}{8}$ in. may obtain, the material is much too "sharp," to use a practical expression, and it becomes quite impossible to temper down to requirements if the accepted temperatures are observed.

The reason for the foregoing is owing to the fact that while the forgings are yet too hard from the top tempering limits, still further heat increments result in the hardness increasing, due to the air-hardening propensities involved even at such low temperatures.

TABLE II.
Physical properties required of Specification 4 811.

0·1% proof stress	43 tons/sq. in.
Ultimate stress	55–65 tons/sq. in.
Elongation	18% minimum.
Izod (Impact)	40 ft.lb. minimum.
Brinell hardness	248—302.

In amplification of these remarks, some results obtained on a small forging will be described. The description and dimensions of the latter were a small disc roughly 3 in. in diameter × $\frac{1}{4}$ in. in thickness, with a concentric boss in centre of $\frac{7}{8}$ in. diameter, and standing in relief a further $\frac{1}{4}$ in. on each face of the disc.

Quenched initially from 830° C. in oil and tempered at 640° C. for 2 hours, Brinell impressions down to 3·10–3·30 mm. were obtained, corresponding to 341–388 B.H.N. As is probably well known, approximately 645° C. is about the maximum limit for 4S11 before re-hardening after tempering takes place, and the instance in question proved no exception to the rule as the discs from 650° C. were roughly half-a-point Brinell impression harder than from the lower temperature.

The only possible recourse was to re-quench from a lower temperature, and this was done experimentally until a point was reached where the required hardness was obtained after a 640° C. temper. It became, therefore, a question of making standard the tempering temperature at 640° C.

[1] METALLURGIA, September, 1941.
[2] METALLURGIA, November, 1941.

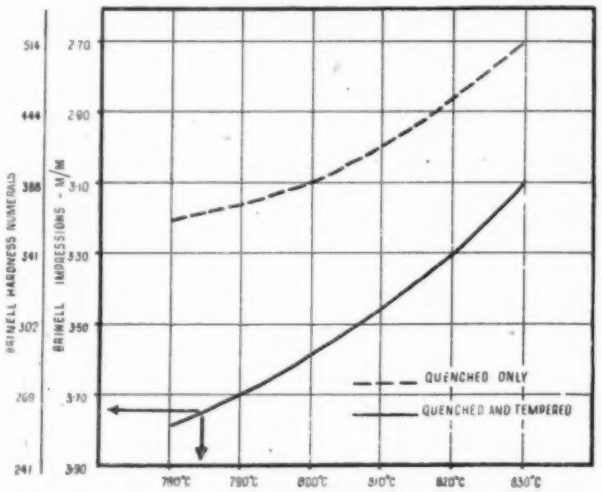


Fig. 1.—Brinell hardness values obtained from various quenching temperatures all tempering at 640° C.

and adjusting the quenching temperature for hardening until the Brinell and consequently the tensile conformed. The highest possible tempering point was maintained in order to ensure good Izod impact figures, and that this object was achieved was indicated by the latter averaging between 80 and 90 ft.-lb.

The results of the investigation are shown graphically in Fig. 1, and may serve as a help to others who may be confronted with difficulties of a similar character.

From these figures it will be noted that the use of 780° C. as a quenching temperature resulted in satisfactory Brinell hardnesses being obtained, and 780°–790° C. has since been adopted as standard for ruling thicknesses of similar character, followed by a 640° C. temper. In regard to the latter, much superior results have been forthcoming by increasing the tempering soaking period to 3 hours, followed by air cooling.

It may be argued that there is some risk of hardening not taking place correctly on the initial quench from a low temperature, but this is not so when the mechanical properties are forthcoming. In Table III are given the actual figures obtained on a 1 in. diameter test-piece governing a batch of the discs under discussion. If the greater dimensioned test-piece were capable of yielding the results, it may be accepted that the forgings would also.

TABLE III.
Physical properties of 1 in. diameter Test Bar in Specification 4 811 after quenching from 780° C. 1½ hours soak, in oil and tempering 640° C., 3 hours soak, and cooling in air.

Ultimate stress	62·2 tons.
Elongation	22·0%
Izod (Impact)	82, 80, 78 ft.-lb.
Brinell hardness	285 (10 mm./3,000 kgs.).

In certain cases where the composition is higher in carbon, nickel and chromium than the average shown, it has even been necessary to air cool after heating for hardening, instead of oil quenching, as even from 760° C. the hardness may be too pronounced to allow the maximum tempering temperature to be effective. In such cases it is not uncommon to obtain hardness figures up to 461 Brinell, which surely is an indication of the hardening propensities. Small wonder that En. 16 is the alternative specification now put forward, where nickel is absent, but whether such is capable of figures to equal those shown in Fig. 1 is a matter for further investigation.

The Chemical and Physico-Chemical Analysis of Iron and Steel

Twelve Years' Advancement

Part II.(*Contd.*)—Papers Describing the Determination of Single Constituents

By E. C. Pigott

Cobalt

The classical zinc oxide-nitroso-β-naphthol method received little attention but Heymans found in 1929 that occlusion was overcome by adding the ZnO to a cold, moderately dilute, solution. Several investigators favoured precipitation as hydrated cobaltic oxide, a separation impaired by a number of constituents. The cyanometric method, formerly unpopular, has been modified by Evans. A variety of physico-chemical methods include polarographic determination.

PRECIPITATION AS HYDRATED COBALTIC OXIDE.

Bartrand. *Bull. Soc. Chim. Belg.*, 1929, **38,** 364.
(Separation from Ni by means of Br and Zn salts.)

Hoffman. *Bur. Stand. J. Res.*, 1932, **8,** 659.
(Ether or ZnO separation followed by treatment with Na_2O_2, with cupferron, and finally, nitroso-β-naphthol.)

Malaprade. *Bull. Soc. Chim.*, 1930 (iv), **47,** 405.
(Treatment with H_2O_2 and then either alkali or $Na_2H_4IO_6$ with subsequent iodometric titration.)

Malor and Eliseev. *Zavod. Lab.*, 1938, **7,** 145.
(After the addition of chlorinated alkali, titration with ferrous solution and $KMnO_4$.)

CYANOMETRIC METHODS.

Evans. *Analyst*, 1937, **62,** 363.

Gel'band. *Zavod. Lab.*, 1934, **3,** 129.

Jaboulay. *Rev. Met.*, 1937, **34,** 166.
($Co_3Na_{12}(CN)_{24}$ is furnished, the excess of KCN being titrated with $AgNO_3$.)

POTENTIOMETRIC.

Dickens and Maassen. *Arch. Eisenhüttenw.*, 1936, **9,** 487.

Steele & Phelan. *Gen. Elec. Review*, 1939, May, **42,** 218.
(A modification of the Dickens and Maassen procedure.)

PHOTOMETRIC.

Bischof and Geuer. *Angew. Chem.*, 1941, **54,** 238.
(Formation of rose-coloured amino complex after ZnO sepn.)

Pinsl. *Arch. Eisenhüttenw.*, 1940, **13,** 333.
(Involves the ZnO separation; blue coloration with $SnCl_2$.)

PRECIPITATION WITH α-NITROSO-β-NAPHTHOL.

Heymans. *Natuurwetensh Tijds.*, 1929, **11,** 151.
(Occlusion in the ZnO separation obviated by precipitating in cold, dilute solution.)

PRECIPITATION AS COBALTONITRITE.

Nikolaw. *Przemysl Chem.*, 1933, **17,** 46.
(The precipitate is oxidized with $KMnO_4$ and the MnO_2 determined iodometrically).

THIOCYANATE—PYRIDINE PRECIPITATION.

Mukhina. *Zavod. Lab.*, 1935, **4,** 150.
($Co(CNS)_2$—$4C_5H_5N$ formed in tartrate solution; inapplicable to materials rich in nickel.

CONVERSION TO $CoSO_4$.

Lehr. *Ann. Chim. anal. appl.*, 1935, **17,** 117.
(Preliminary precipitation of CoS.)

MICROCHEMICAL.

Feary. *Mikrochem.*, 1934, **15,** 141.
(A review of methods.)

POLAROGRAPHIC.

Maassen. *Angew. Chem.*, 1937, **50,** 375.
(Seven references).

Hanheiser and Maassen. *Arch. Eisenhüttenw.*, 1937, **10,** 441; also *Mitt. K. W. Inst. Eisenfor.*, 1937, **19,** 27.

DETERMINATION IN ORES.

Karle and Tal. *Zavod. Lab.*, 1939, **8,** 383.
(Small amounts estimated electrolytically or colorimetrically.)

Columbium

Amounts of columbium up to 1% or about 10 times the carbon content are added in order to inhibit "weld decay" in stainless steels and irons. The separation of this element from tantalum, so very closely allied in reactions, has been the subject of exhaustive and invaluable researches by Schoeller and Powell and their collaborators, leading to an important method of precipitation as a tannin adsorption complex. Recently, Cunningham has developed a modification of their procedure and has also proposed a reliable cupferron method. In addition, photometric and spectrographic methods have been devised.

REVIEW OF METHODS.

Klinger. *Tech. Mitt. Krupp. Forsch.*, 1939, **2,** 171.

Taylor-Austin. *B.C.I.R.A. Res. Rep.*, 1939, 6033.
(In pig iron and cast iron.)

PRECIPITATION AS OXALO-COLUMBIC ACID.

Schoeller and Powell. *Analyst*, **53,** 515; **60,** 506; **50,** 485; **52,** 504 and 625.

PRECIPITATION BY MEANS OF CUPFERRON.

Cunningham. *Ind. Eng. Chem. Anal. ed.*, 1938, **10,** 233–5.

Silverman. *Ind. Eng. Chem. Anal. ed.*, 1934, **6,** 287.

PHOTOMETRIC.

Klinger and Koch. *Arch. Eisenhüttenw.*, 1939, **13,** 127–134.
(Measurement of the orange-red percolumbate obtained with hydrogen peroxide. The method is preceded by a review of available separations.)

Thanheiser. *Mitt. Kaiser Wilhelm Inst. Eisnf. Düsseldorf*, 1940. **22,** 255.
(Yellow coloration with H_2O_2 in $H_2SO_4 + H_3PO_4$.)

Copper

Recent literature devoted to the estimation of this constituent is rich in modifications of the various established chemical methods and in new physico-chemical technique.

Numerous organic precipitants have been applied. Foote and Vance have contributed an important paper on the influence of As, Sb, and Fe in the iodometric method. Attention is drawn by Shportenko and Garen to the partial solubility of copper in dilute H_2SO_4 even when oxidation is suppressed by means of iron wire.

REVIEWS OF METHODS.

Frommes. *Z. anal. Chem.*, 1934, **97,** 36–49.

Matveev. *Tzvet. Metal*, 1930, 1491.
(85 references.)

IODOMETRIC.

Cromwell, *et al. Ind. Eng. Chem. Anal. ed.*, 1938, **10,** 80.
(At *p*H 3·3, up to 0·3 *g* of Fe is permissible.)

Foote and Vance. (i) *Ind. Eng. Chem. Anal. ed.*, 1936, **8,** 119.
(Influence of As, Sb, Fe.)

Foote and Vance. (ii) *Ind. Eng. Chem. Anal. ed.*, 1937, **9,** 205.
(Unmodified iodofluoride procedure fails where the amount of iron exceeds 0·15 g. Titration methods tend to give low results.)

Joan. *Chem. Zentr.*, 1934, II, 1959.
($(Na_2S_2O_3$ precipitation promoted by $HgCl_2$; subsequently precipitated as CuCNS, the excess KCNS being determined by conversion with NaBrO to cyanate and this estimated iodometrically.)

Lipschuetz. *Chemist-Analyst*, 1937, **26,** 57.
(Iron interference suppressed by conversion to fluoride.)

Whitehead and Miller. *Ind. Eng. Chem. Anal. ed.*, 1933, **5,** 15.
(The titration is unaffected by moderate amounts of H_2SO_4 and AcOH.)

ALTERNATIVE CuS METHODS.

Brüggemann. *Chem. Ztg.*, 1933. **87,** 863.
(Cyanometric.)

Castiglioni. *Z. anal. Chem.*, 1934, **97,** 270.
(Colorimetric, using $(NH_4)_2S$.

Knoyle. *Metals and Alloys*, **1**, 738.

Shportenko and Garan. *Zavod. Lab.*, 1938, **7,** 1199.
(Cyanometric.)

ORGANIC REAGENT PROCESSES.

Bagshaw. *J. Soc. Chem. Ind.*, 1938, **57,** 260.
(By diethyldithiocarbamate; Lovibond Tintometer.)

Hoar. *Analyst*, 1937, **62,** 788.
(By diethyldithiocarbamate.)

Kar. *Ind. Eng. Chem. Anal. ed.*, 1935, **7,** 193.
(Precipitation by benzoin-oxime in ammoniacal solution.)

Zan'ko and Bursuk. *Zavod. Lab.*, 1937, **6,** 675; *Ber. Inst. Physik Chem. U.S.S.R.*, 1938, **9,** 89.
(By means of 5, 7-dibromo-o-hydroxyquinoline.)

Zan'ko and Butenko. (i) *Zavod. Lab.*, 1937, **6,** 545.

Zan'ko and Butenko. (ii) *Ber. Inst. physik Chem. Akad. Wiss. Ukr. S.S.R.*, 1938, **9,** 99; *Khim. Referat. Zhur.*, 1939, **2,** No. 3, 73.
(In cast iron and steel by pptn. with quinaldinic acid from H_2SO_4—tartrate solution.)

Spacu. *Bull. Soc. Chim.*, 1936, (**5,**) 3, 1061.
(Fe, precipitated as $Fe(OH)_3$ by pyridine and Cu as $Cu\ Py_4(SCN)_2$ from the filtrate.)

Spacu and Macarovici. *Chem. Zentr.*, 1937, **11,** 3784.
(Benzidine precipitation.)

Spacu and Niculescu. *Z. anal. Chem.*, 1939, **116,** 119.
(Precipitation with $K_2Cr_2O_7$ and pyridine as $CuPy_4Cr_2O_7$.)

Stengel. *Tech. Mitt. Krupp.*, 1939, **2,** 87.
(Precipitation by salicylaldoxime from tartrate-acetate solution.)

Stott. *Foundry Trade J.*, 1940, **63,** 128.
($Na_2S_2O_3$—α-benzoin-oxime.)

ELECTROLYTIC.

Anderson. *Chemist-Analyst*, 1931, **20,** No. 2, 7.

Fife and Torrence. *Analyst*, 1937, **62,** 29.

Geloso. *Bull. Soc. Chim.*, 1939, **6,** 1238.

Smekh and Naigovgen. *Zavod. Lab.*, 1940, **9,** 1218.

Vorontsova. *Zavod. Lab.*, 1937, **6,** 875.

POTENTIOMETRIC.

Met. ital., 1935, **27,** 707.
(Involving formation of $Cu_2(CN)_3K_3NH_4$.)

Schaefer. *Arch. Eisenhüttenw.*, 1937, **11,** 297.
(14 references.)

Weihrich. *Arch. Eisenhüttenw.*, 1940, **14,** 55.
(To eliminate use of KI in cyanometric method, electrodes of AgI and Ag.)

POLAROGRAPHIC.

Thanheiser and Maassen. *Arch. Eisenhüttenw.*, 1937, **10,** 441.

Maassen. *Angew. Chem.*, 1937, **50,** 375.
(7 references.)

Asatenko and Lyalikod. *Zavod. Lab.*, 1937, **6,** 1394.
(Modification of Thanheiser-Maassen procedure.)

PHOTOMETRIC.

Bogatzki. *Arch. Eisenhüttenw.*, 1941, **14,** 551.
(As colloidal CuS; in iron and alloy steels.)

Ke me. Reprint, *Carl Zeiss, Jena. Mess.*, 762.
(Pipt. of Cu_2S ignited, dissolved in $HCl + HNO_3$ and solution treated with NH_4OH.)

Dietrich and Schmitt. *Z. anal. Chem.*, 1937, **109,** 25.
(As cupra-ammonium complex.)

SPECTROGRAPHIC.

Aleksandrov and Reisl'ii. *Zavod. Lab.*, 1936, **5,** 755.

Hydrogen

Practically all irons and steels contain hydrogen, in amounts ranging from 0·0001 to 0·002%. Average values found by Chiu and Willems were 0·00017% in acid open-hearth steel; 0·00015% in basic open-hearth; 0·00018% in duplex steel; and 0·00013% in basic electric steel. It is usual to isolate the gases by means of vacuum extraction (now a very reliable process) and then to determine the H_2 volumetrically. Alternatively, the H_2O, evolved on direct ignition in oxygen, is absorbed in P_2O_5.

Chiu and Willems. *Arch. Eisenhüttenw.*, 1939, **12,** 485.
(Modification of vacuum extraction method.)

Eilander and Diegarten. *Arch. Eisenhüttenw.*, 1931, **4,** 587.
(Hot extraction method is not affected by Mn up to 0·6% or Al up to 0·2%.)

Gerke and Zolotareva. *Zavod. Lab.*, 1935, **4,** 19.
(30–50 g. ignited at 700°–800° C. in O_2 and the H_2O absorbed in P_2O_5.)

Holm and Thompson. *J. Res. Nat. Bur. Stand.*, 1941, **26,** 245–59.
(Vacuum extraction at 800° C. or vacuum fusion; latter unsuitable for unstable H_2, for which former is preferable.)

Kalling and Rudberg. *Jerkontorets Ann.*, 1938, **122,** 91.
(2% H_2 in gas obtained from O.H. furnace corresponds to 0·00035% H_2 in bath.)

Kobayasi. *Tetsu-to-Hagane*, 1939, **25,** 745–73.
(Vacuum-fusion at 800° C. most suitable.)

Lebedev. *Zavod. Lab.*, 1935, **4,** 267; 1938, **7,** 1378.
(Improvements in ignition furnace and Hg-vacuum pump.)

Lucas, Grassner and Neukirch. *Mikrochem*, 1930, 197.
(Titration of HCl evolved from naphthyloxychloride.)

Meyer and Williams. *Arch. Eisenhüttenw.*, 1937, **11,** 259
(Modified furnace with carbon heating coil, designed to preclude development of H_2.)

Newell. (i) *J. Iron Steel Inst.*, 1940; *Engineering*, 1940, **149,** 479.

Newell. (ii) *J. Iron Steel Inst.*, 1941, 26.
((i) Vacuum heating at 600° C.; fusion involves "blank" errors.)
((ii) Improved Hg vapour pump for vacuum heating method.)

Sloman. *J. Iron Steel Inst.*, 1941, 4–18.
(Reliability of vacuum fusion method for H_2 open to some doubt.)

Tawara. *Tetsu-to-Hagane*, 1939, **25,** 413.
(Vacuum heating method is preferable to vacuum fusion or combustion; 50–100 g. at 800° C. for 1–2 hours in high vacuum and gases analysed in small Orsat app.)

Thanheiser. *J. Iron Steel Inst.*, 1936.
(17 references. A review of methods.)

Thanheiser and Ploum. I. *Arch. Eisenhüttenw.*, 1937, **11,** 81.

Thanheiser and Ploum. II. *Mitt. K. W. Inst. Eisenfor.*, 1937, **19,** 105.
(Review of methods: modified Orsat app. described.)

Thompson. *Amer. Inst. Mining Met. Eng. Inst., Metals Division Tech. Pub.*, 1932, **466,** 22 pp.
(A comparison of methods.)

Veinberg and Proshutinskii. *Zavod. Lab.*, 1937, **6,** 422.
(30 references. Modification of Gerka-Zolotareva method described in detail.)

Ziegler. *Trans. Elektrochem Soc.*, 1932, **62,** 13 pp.
(Gases, extracted by melting sample in vacuo in graphite crucible, analysed by selective freezing process.)

Iron

Amongst several established methods studied and modified, the cupferron and zinc procedures were re-examined. Johnson has evolved a perchloric acid-sulphurous acid method, unaffected by Cr, Ti, Mo and W. In the titration of ferrous iron, brucine has been found to be a reliable indicator, possessing a wide permissible latitude in regard to acidity. Numerous contributors considered the analysis of mixtures of the oxides.

VOLUMETRIC REDUCTION METHODS.

(*a*) *Perchloric Acid Procedures:*

Johnson. *Iron Age*, 1939, **144,** No. 15, 3031.
(Detn. in steel, alloy steel and ferro-manganese.)

Peters. *Chemist-Analyst*, 1937, **26,** 6–10.

Scott. *Chemist-Analyst*, 1935, **24,** 4–6.

(*b*) *Reduction with Zinc:*

Truog and Pearson. *Ind. Eng. Chem. Anal.*, ed., 1938, **10,** 631.
(In presence of Ti.)

(*c*) *Brucine as Indicator:*

Alekseeva and Andronikov. *J. Applied Chem.* (U.S.S.R.), 1938, **11,** 1024.

(*d*) *Potentiometric:*

Khlopin. *Zavod. Lab.*, 1936, **5,** 580.
(In ferro-chrome.)

Martynchenko and Shimko. *Zavod. Lab.*, 1936, **5,** 1297.

GRAVIMETRIC (PRECIPITATION WITH CUPFERRON).

Pigott. *Ind. Chem.*, 1935, **11,** 273.

ETHER SEPARATION.

Shadrina. *Trudy Vsesayug, Nauch-Issl. Inst. Metrol.*, 1937, No. 15, 15–19.
(In high nickel steels.)

ANALYSIS OF MIXTURES OF IRON OXIDES.

Karjakin and Vinogradov. *Z. Anal. Chem.*, 1936, **107,** 181.

Kaufmann. *C.A.*, 1933, 2112.

Leiba and Dolgina. *Zavod. Lab.*, 1935, **4,** 743.

Maurer. *C.A.*, 1935, 3258.

Tazawa. *Seitetsu Kenkyu*, 1933, No. 134.

IRON OXIDE IN LIQUID STEEL.

Harty, Freeman and Lightner. *Bur. Mines Rept. of Invest.*, 1932, 3166.

ELECTROLYTIC DETERMINATION IN TUNGSTEN.

Holt and Swalheim. *Ind. Eng. Chem. Anal. ed.*, 1939, **11**, 254.

METALLIC IRON IN BLAST FURNACE SLAG.

Budniker and Mal'nikova. *J. App. Chem.* (U.S.S.R.), 1940, **13**, 1732.
(Extraction in neutral $CuSO_4$.)

Riatt. *Ind. Eng. Chem. Anal. ed.*, 1941, **13**, 546.
(In slags and oxides; K_2CuCl_4 extraction.)

Lead

A recent development is the addition to both plain and alloy steels of amounts around 0·25% to effect greater machinability, the mechanical properties being unimpaired. In the application of classical methods to ferrous analysis, practical details have been evolved for precipitation as sulphide with conversion to the molybdate, a very reliable procedure.

Mumsey and Gordon. *Chemist-Analyst*, 1940, **29**, 62.
(H_2SO_4—$PbMoO_4$.)

Pavlish. *Metals and Alloys*, 1939, **10**, 150.
(In carbon steels.)

MICROCHEMICAL.

Kraus. *Z. ges. exptl. Med.*, 1935, **95**, 434.

SPECTROGRAPHIC.

Breckpot & Mevis. *Ann. soc. Bruxelles*, 1934, 54B, 290–8.

POLAROGRAPHIC.

Strubl. *Collection Czechoslav. Chem. Commun.*, 1938, **10**, 466–74.

ELECTROLYTIC.

Lundell. *Metal Progress*, 1939, **35**, 383.

Investigations on "Falling" Blast-Furnace Slag

By T. W. Parker, M.Sc., Ph.D., and J. F. Ryder, B.Sc.

An investigation on methods of detecting "falling" blast furnace slags is described in a Report of the Slag Tests Panel to the Blast-Furnace Committee of the Iron and Steel Industrial Research Council. It is confirmed that the basic cause of falling is the inversion of the high-temperature crystalline form of 2 CaO, SiO_2 to the low-temperature form, with corresponding expansion. Measurement of expansion, however, does not provide an accelerated test for falling. Two tests are proposed, both based on using only slag in which no 2 CaO.SiO_2 is present. An abstract of the work is given in this article together with the author's conclusions.*

THE Blast Furnace Committee of the Iron and Steel Industrial Research Council has had under consideration from time to time the question of blast-furnace slags, with respect to both the reaction inside the furnace and the utilisation of the slag when made. In the past a number of British blast-furnace slags have not been marketed, largely because of their inability to disintegrate when air-cooled, which makes them unsuitable for use in tar macadam, or as concrete aggregate. Other slags, while usually quite suitable for these purposes, occasionally had a proportion of material which disintegrated and thereby became unsuitable.

The matter was referred to a Panel of the Blast-Furnace Committee. The terms of reference of this Panel were: (1) To examine methods of rapid testing of air-cooled slags, particularly with regard to disintegration; and (2) to examine whether, by suitable methods of foaming, unstable slags could be stabilised. A report on the latter was published in 1937,† in which it was shown that stable products could be made by the foaming process, even from unstable slags. The first item has been the subject of detailed investigation, and the conclusion shows that concrete of satisfactory quality can be made from blast-furnace slag aggregate, provided the latter satisfies certain requirements which can be assessed by laboratory tests. As a result of the work it has been found possible to devise two new tests, both of which require certain technical facilities for their operation, but which should not be impossible to carry out as a control measure in works practice.

An essential requirement of any concrete aggregate is that it should be stable. Certain slags are, therefore, at once ruled out as unsuitable because they disintegrate after solidifying from the molten state. At its worst this results in the originally rock-like mass being converted entirely into a coarse powder. Such slags are termed "falling" slags in the industry. It is highly desirable that there should be a test by which falling slags can be distinguished at an early stage after production. The possibility of devising such a test was the main object of this investigation.

* Iron and Steel Institute, Advance paper, July, 1942.
† T. W. Parker: Iron and Steel Institute, 1937, Special Report No. 10.

The authors discuss previous experiences and consider the cause of falling before describing various tests for falling slag. Volume-expansion tests were made, using a dilatometer technique, and the results indicated that the dilatometer test does not provide a suitable routine test of falling. Liquid-immersion tests, devised by Guttmann, were investigated, but the authors concluded that this test is not one which could be applied as a reliable accelerated test of falling. Another test, previously proposed by Guttmann, making use of the ultraviolet lamp, was also examined, and, on the basis of the results obtained, it was concluded that this test is not an entirely safe guide to falling slags.

Two new tests are proposed, both based on using only slag in which no 2 CaO.SiO_2 is present. One of these, suitable for slags which are cooled slowly, e.g., by the "ball" method, depends on the use of an equation, introducing the analytical values for the oxide constituents, and is based on phase equilibrium in the systems, making use of the "suspended equilibrium" hypothesis. In this method it is shown that a slag is safe from falling if its percentage weight composition is such that it conforms to one or both of the following conditions:—

$$\mathrm{CaO} + 0{\cdot}8\,\mathrm{MgO} < 1{\cdot}20\,\mathrm{SiO_2} + 0{\cdot}39\,\mathrm{Al_2O_3} + 1{\cdot}75\,\mathrm{S}.$$
$$\mathrm{CaO} < 0{\cdot}93\,\mathrm{SiO_2} + 0{\cdot}55\,\mathrm{Al_2O_3} + 1{\cdot}75\,\mathrm{S}.$$

The other method is a microscope test with polished specimens etched with a reagent which, in blast-furnace slags, is more or less specific for 2 CaO.SiO_2. Thus, even if slags do not comply with the requirements indicated in the first method, they are safe if they show no 2CaO.SiO_2 etch reaction when polished sections, etched by 10% hot aqueous $MgSO_4$ solution, are examined by reflected light under the microscope.

Since the microscope test overrides the test based on constitution, the latter may be thought to be unnecessary. However, slags are analysed in the normal course of blast-furnace operation, and the test, based on constitution only, requires a calculation from this analysis. If the slag is shown to be safe by this test it is not necessary to carry out the more complicated operations of the microscope test; thus the former method has advantages in convenience.

Some Modern Methods of Metallurgical Analysis

(*Continued from page* 120.)

The method cited above is that due to Vaughan,[1] and his paper should be consulted for full details with regard to the estimation of a number of elements in ferrous, non-ferrous, and light alloys. A very comprehensive survey of the present position, using this instrument, is given, together with limits of accuracy, comparison with other methods, reagents used, and the speed with which analysis can be carried out.

The instrument is being used at the moment in industry for the following estimations :—

Ferrous Alloys.—Manganese, chromium, nickel, vanadium, copper, titanium, molybdenum and phosphorus. As previously mentioned, with one single filtration the above elements can be estimated in ordinary and alloy cast irons. It will be noticed that up to the time of writing methods are not available for carbon, sulphur and nitrogen.

Non-ferrous Alloys.—Manganese, nickel, phosphorus and iron in brasses and bronzes.

Light Alloys.—Silicon, manganese, copper, iron, nickel, titanium and magnesium in aluminium alloys.

Space considerations will not allow of an elaboration of the various methods employed, but one or two examples are given. In the case of steels, the complete estimation for manganese as permanganate has been described. Regarding non-ferrous materials, a useful example is phosphorus in phosphor bronzes. The drillings, etc., are taken into solution and the phosphorus converted to phosphoric acid and thence to ammonium phosphomolybdate. This is suitably reduced to the molybdenum blue complex, the intensity of which is a measure of the amount of phosphorus present in the sample.

Concerning light alloys, the absorptiometer allows of a very rapid method for the estimation of silicon. A solution of the light alloy is made in caustic soda, the solution acidified, silico-molybdates formed by the addition of ammonium molybdate, and these transformed to molybdenum blue, the intensity of the latter being proportional to the amount of silicon in the light alloy.

In all the methods indicated so far, the coloured solutions have been produced directly after solution of the sample in question, and in no case is precipitation or separation necessary, thus giving results which, whilst of an order of accuracy comparable with gravimetric methods, are much more speedy. The scope of the absorptiometer is only limited by the ability of an element to form coloured solutions—which may be produced directly or indirectly—which give an absorption proportional to the concentration of the element present. It is evident that there is therefore unlimited scope for this instrument in metallurgical analyses when consideration is given to such wide fields as the solders, white metals, nickel-silvers, nickel-chromium alloys, precious metals, magnesium alloys and the like.

Some indication of this scope can be obtained by reference to the most recent literature on the subject. W. G. Fredrick[2] gives a method for antimony by using Rhodamine B ; G. Thanheiser[3] methods for columbium and tantalum in ferrous alloys and slag ; A. S. Shakhov[4] methods for tungsten in steel ; R. Weihrich and W. Schwarz[5] a method for silicon in carbon and alloy steels up to 4% silicon content, to quote but a few representative references.

Further work is in hand on the absorptiometer, the use of special filters and differing light sources being but two examples, whereby higher selectivity and sensitivity may be achieved in metallurgical analysis.

Without doubt, the Spekker Photoelectric Absorptiometer has many advantages which commend it, in that it is run directly off mains supply, the readings on the instrument being independent of fluctuations in such supply. The photocells are of the rectifier type, being extremely robust and durable. The instrument readings are unaffected by variations in the sensitivity of such cells, as a null method is employed. The galvanometer is of the mirror spot type, which whilst being sensitive is of very robust construction. All readings taken are independent of the visual judgment of the operator—a striking difference from colorimeters. Finally, whilst estimations may be carried out on very small quantities of a coloured solution, there is no necessity for comparison against a standard solution for every test, as this work is done when first using the instrument on a particular element and constitutes the calibration graph hereafter for this element. Periodic checks from time to time are a wise procedure, although experience has shown that a calibration graph once taken accurately will suffice for years on the same absorptiometer.

Without doubt, the time is not very far distant when apparatus for absorptiometric analysis will form an integral part of the equipment of every metallurgical laboratory. Suffice it to say in conclusion that although the present instrument cannot be used, at the moment, for the quantitative estimation of every metal met with in metallurgy, it enables results of a degree of accuracy comparable with the best quantitative procedures to be obtained and in a fraction of the time taken by the latter methods.

1 E. J. Vaughan. "The Use of the Spekker Photo-electric Absorptiometer in Metallurgical Analysis." Monograph publ. by Inst. of Chemistry, 1941.
2 W. G. Fredrick. *Ind. Eng. Chem.* (Anal. Edn.), 1941, 13, 922.
3 G. Thanheiser. *Archiv. für das Eisenhüttenwesen*, 1941, vol. 14, p. 371.
4 A. S. Shakhov. *Zavod. Lab.*, 1941, 10, 479. (In Russian.)
5 R. Weihrich and W. Schwarz. *Archiv. für das Eisenhüttenwesen*, 1941, vol. 14, p. 501.

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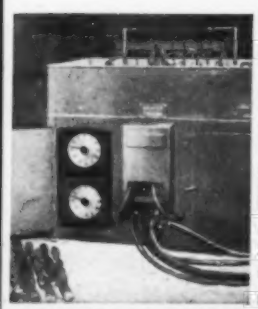

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